Universidad
Católica del Norte

DM HUNTERS

lawphysics
Latin American Webinars on Physics

Dark Matter and its search with astroparticles

Roberto A. Lineros

Departamento de Física, Universidad Católica del Norte

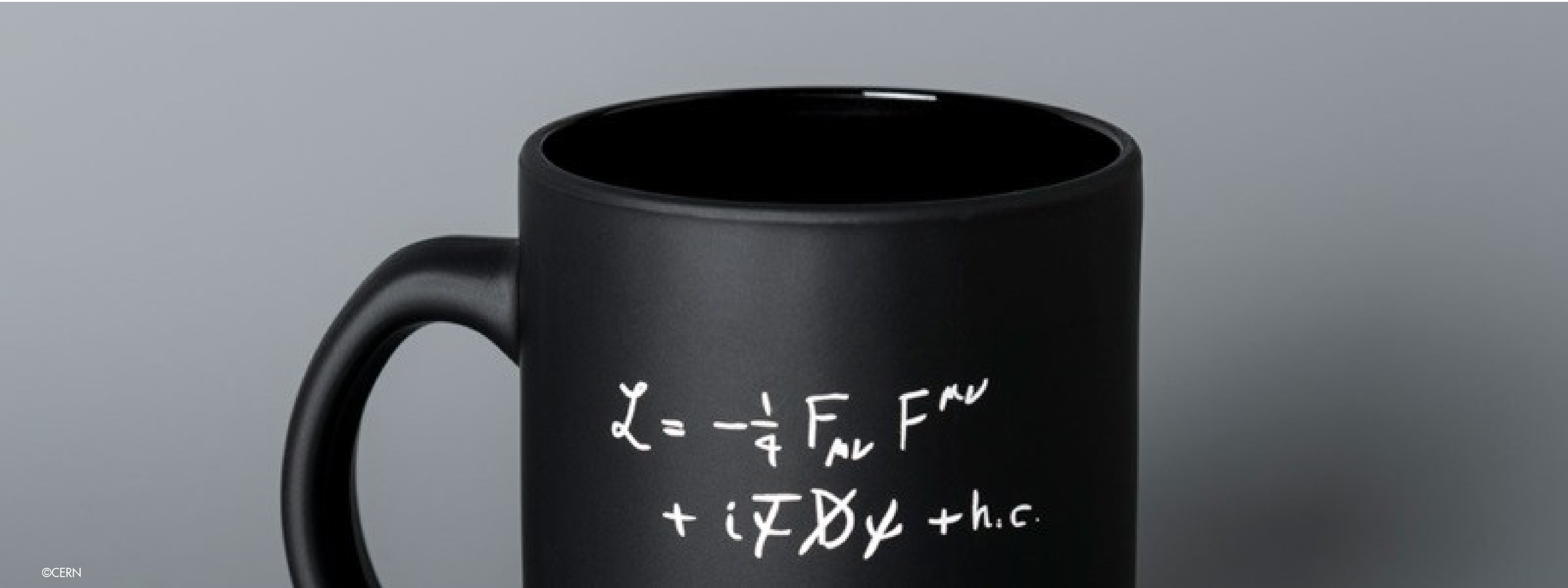
IV Colombian Meeting on High Energy Physics
Barranquilla, Colombia

The Plan

1. Introduction
2. Dark Matter
3. Searches in gamma
4. Searches in radio
5. Conclusions

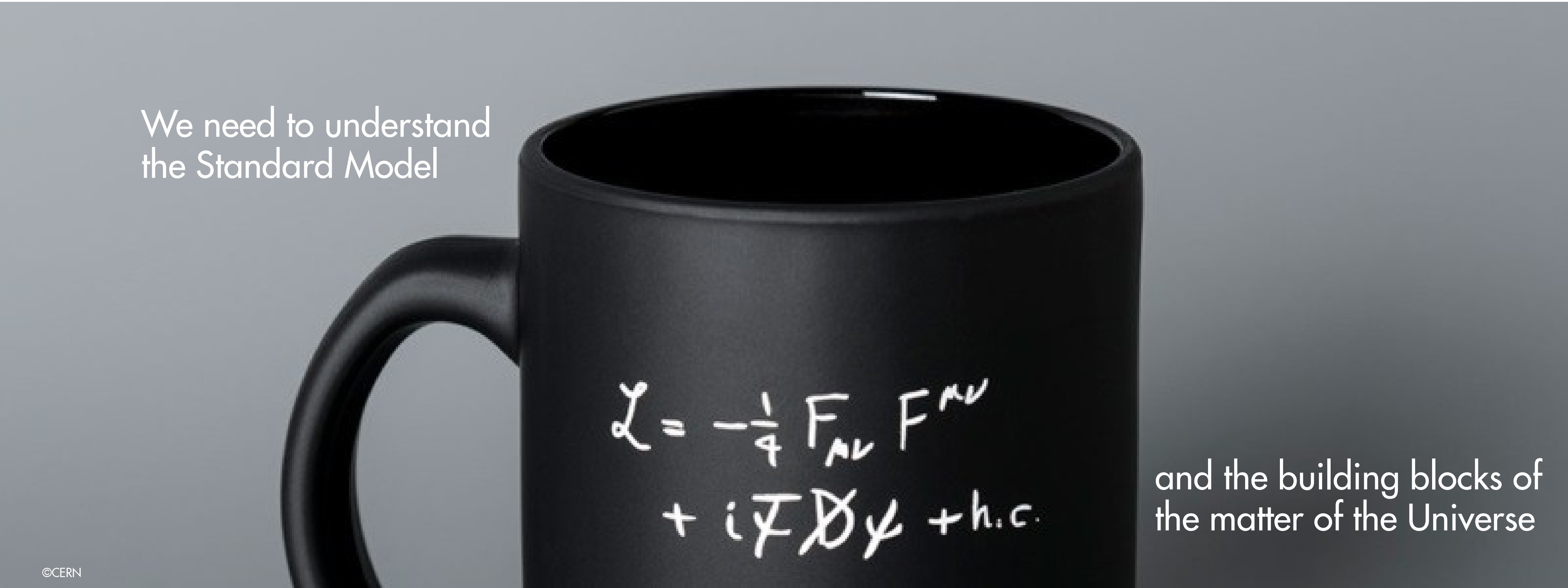
The building blocks

The physics of Universe requires to understand how particles behave.



The building blocks

The physics of Universe requires to understand how particles behave.



We need to understand
the Standard Model

and the building blocks of
the matter of the Universe

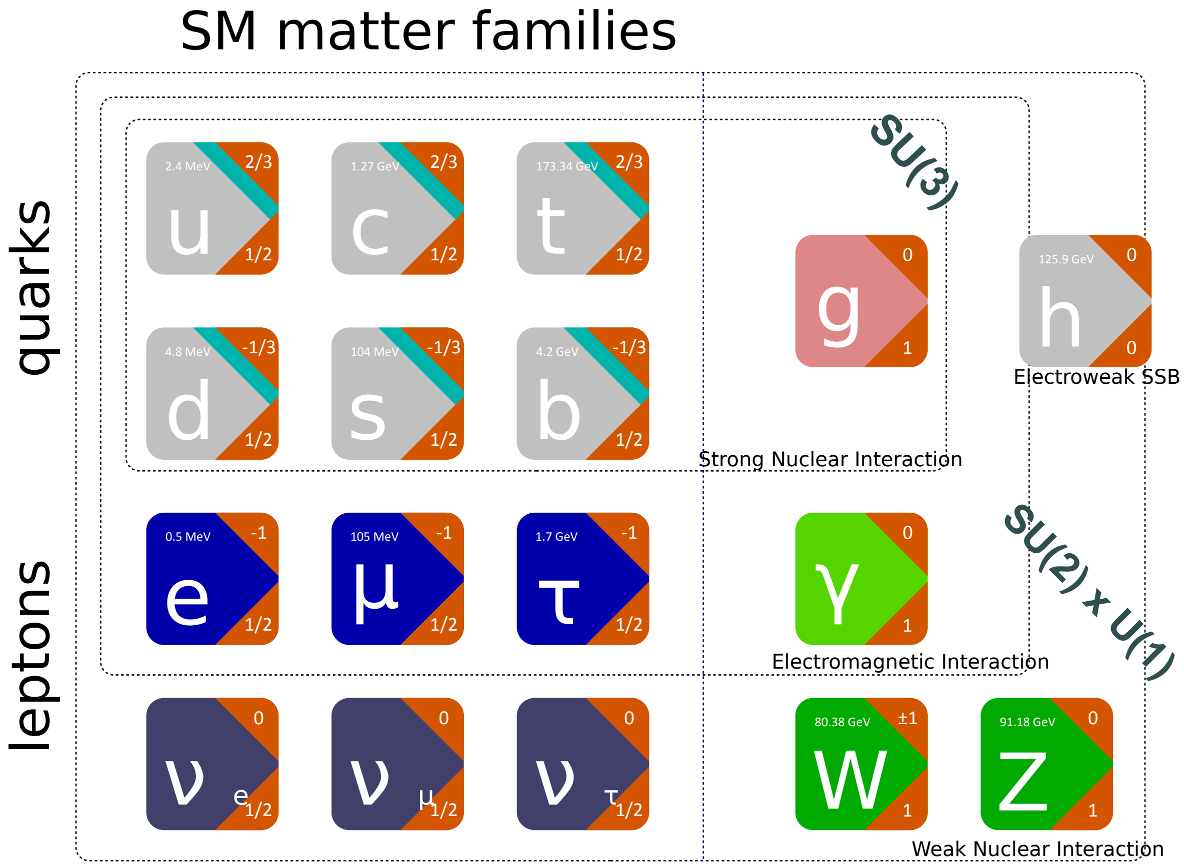
The Standard Model

quarks

leptons

5

The Standard Model

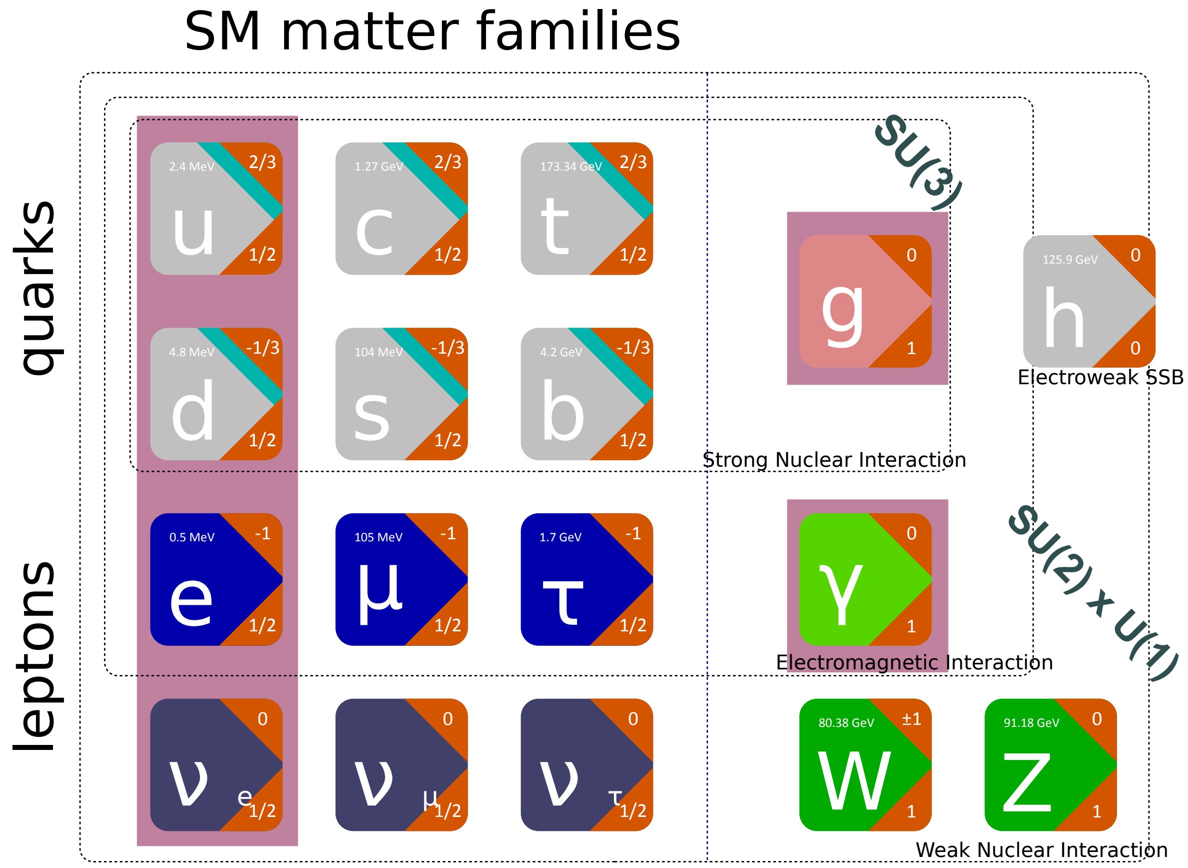


Symmetries
- CPT
- $SU(3)_c$: Color
- $SU(2)_L$: Isospin
- $U(1)_y$: Hypercharge

Matter content
- 3 families quarks
- 3 families leptons

Higgs fields
- $SU(2)_L xU(1)_y \rightarrow U(1)_{EM}$
- Mass to fundamental particles

The Standard Model



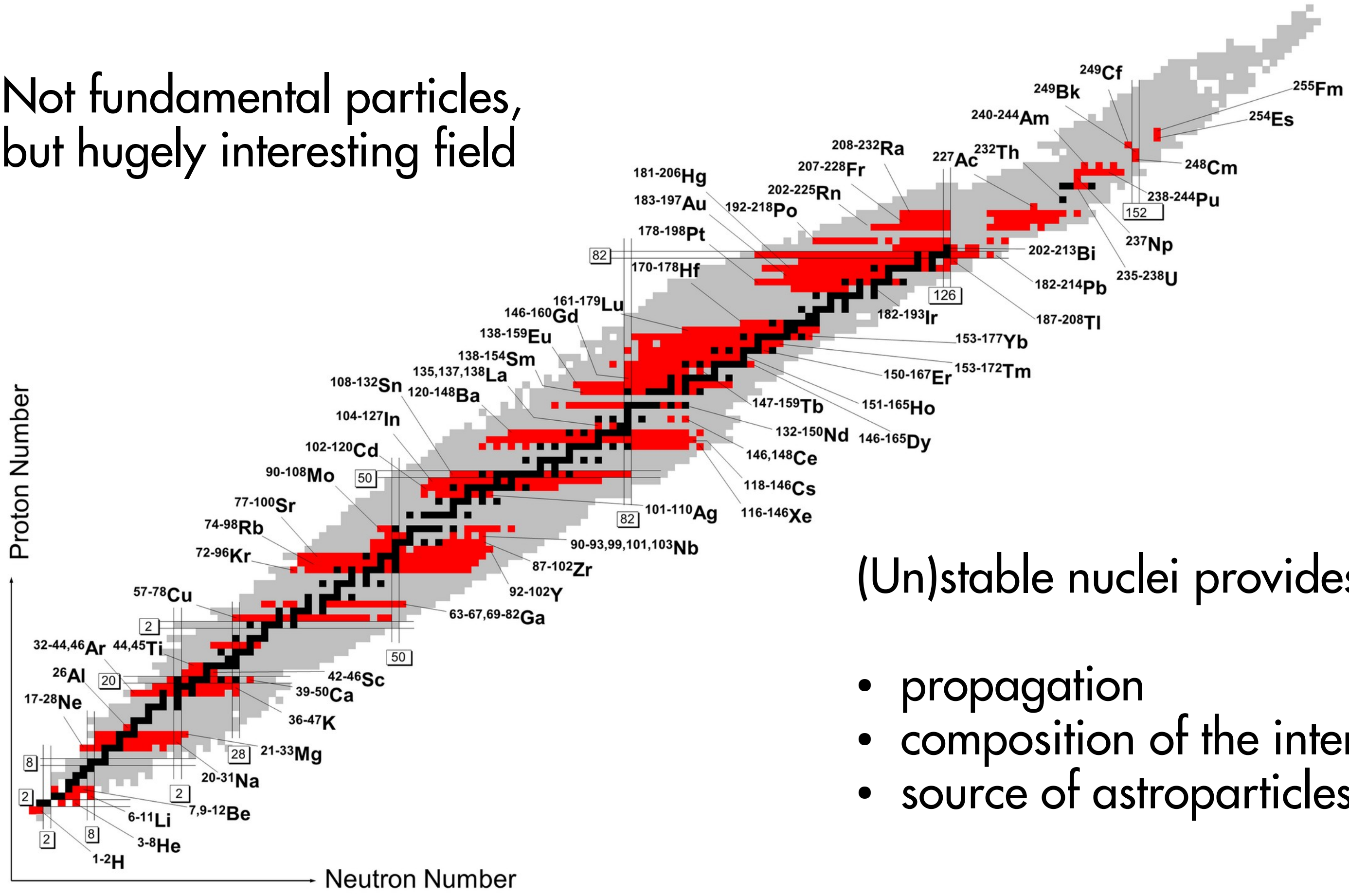
- Massless neutrinos
- Baryon Number
- Lepton Number

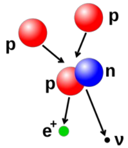
Stable objects:

- Photons
- Electrons, Neutrinos
- Protons (quarks bound states)
- Nuclear matter
- Atoms
- Etc.

Nuclear physics

Not fundamental particles,
but hugely interesting field



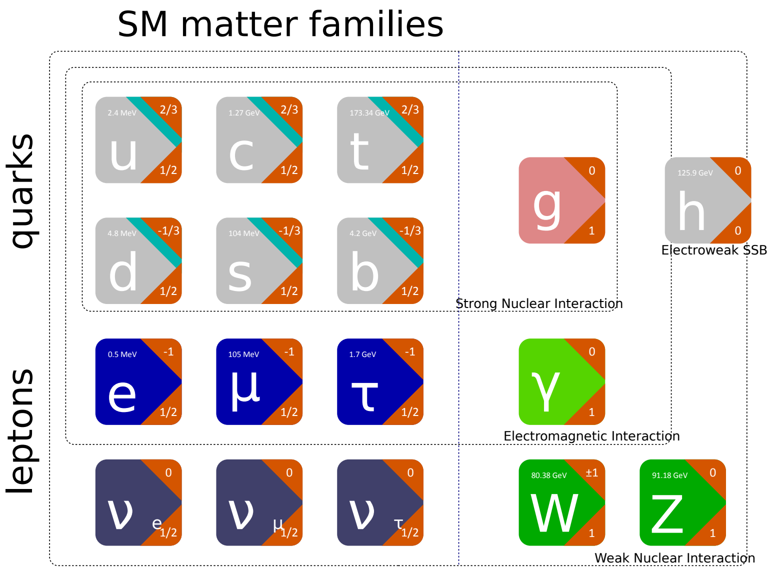


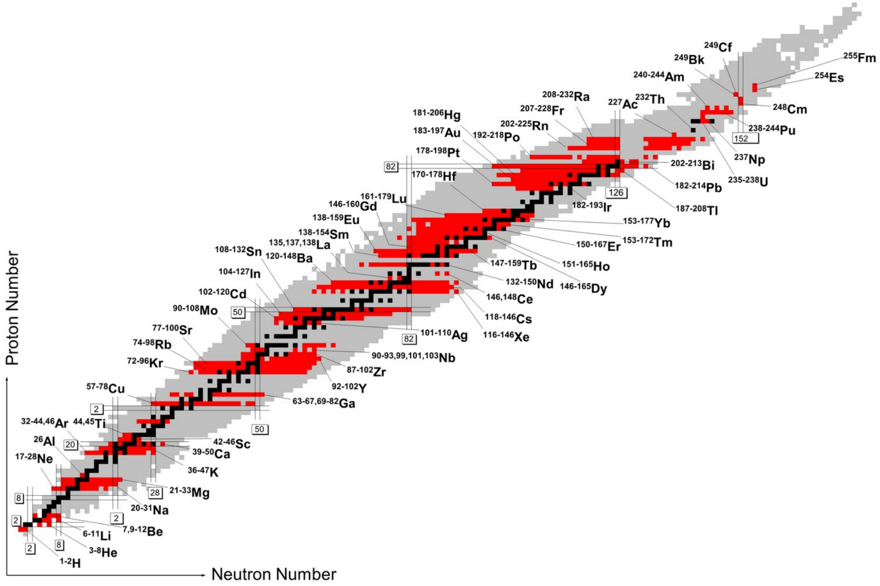
Nucleosynthesis

(Un)stable nuclei provides information about

- propagation
- composition of the interstellar medium
- source of astroparticles

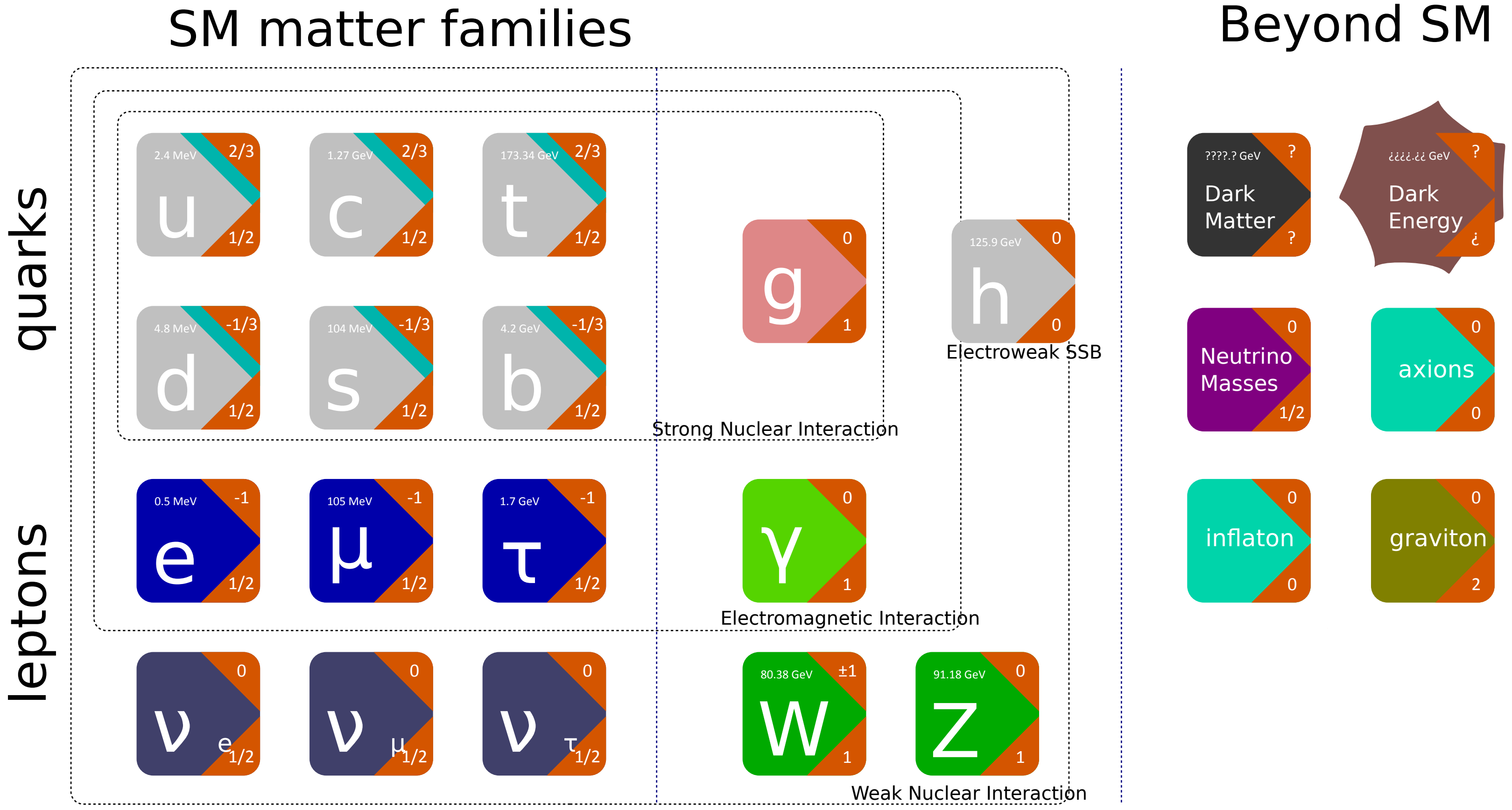
Great success!





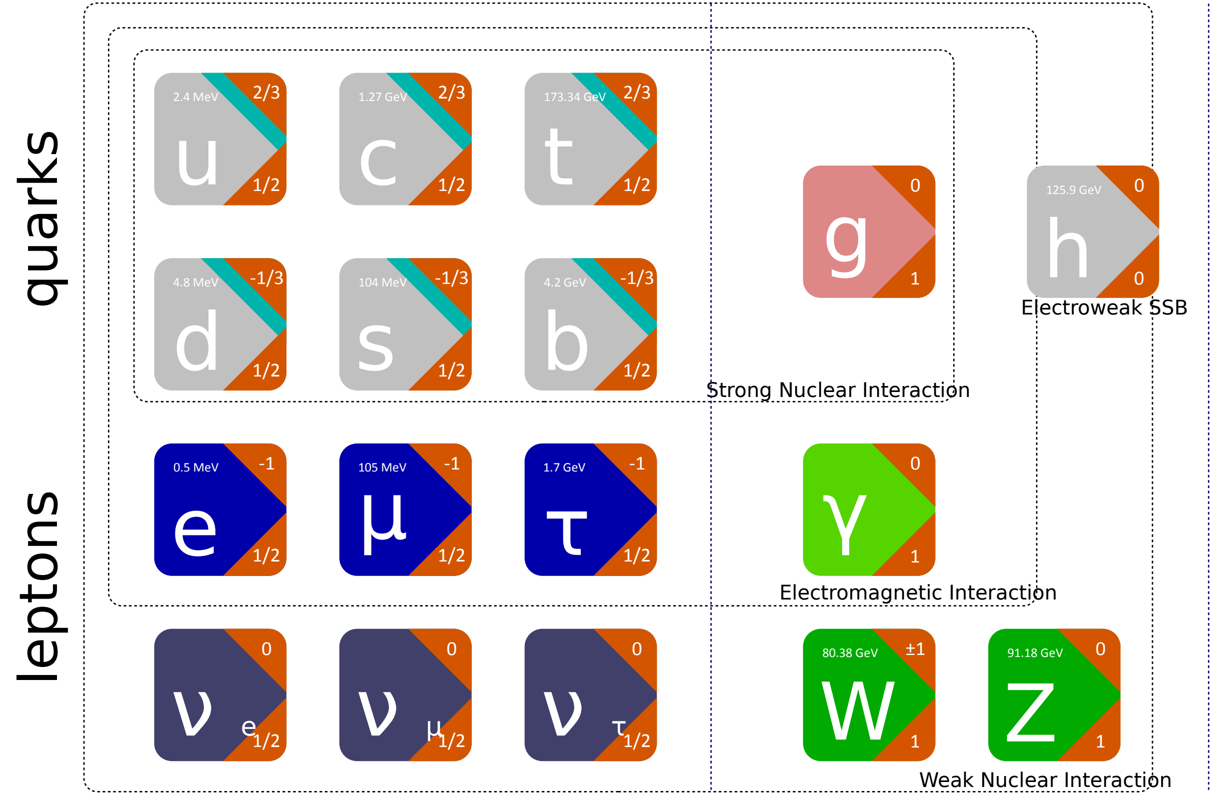
Great description of the smallest components of the Universe and backed up by observations

Not everything is explained

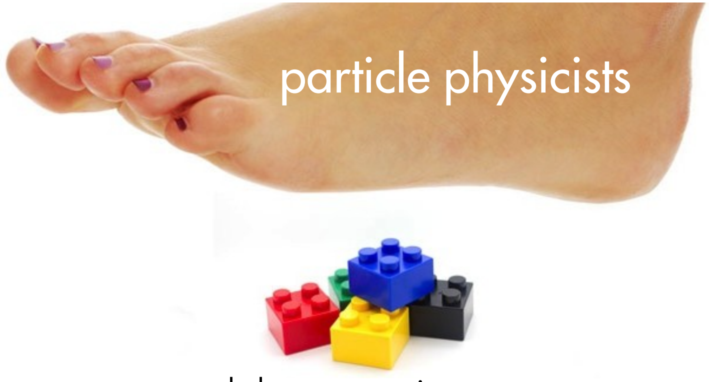


Not everything is explained

SM matter families

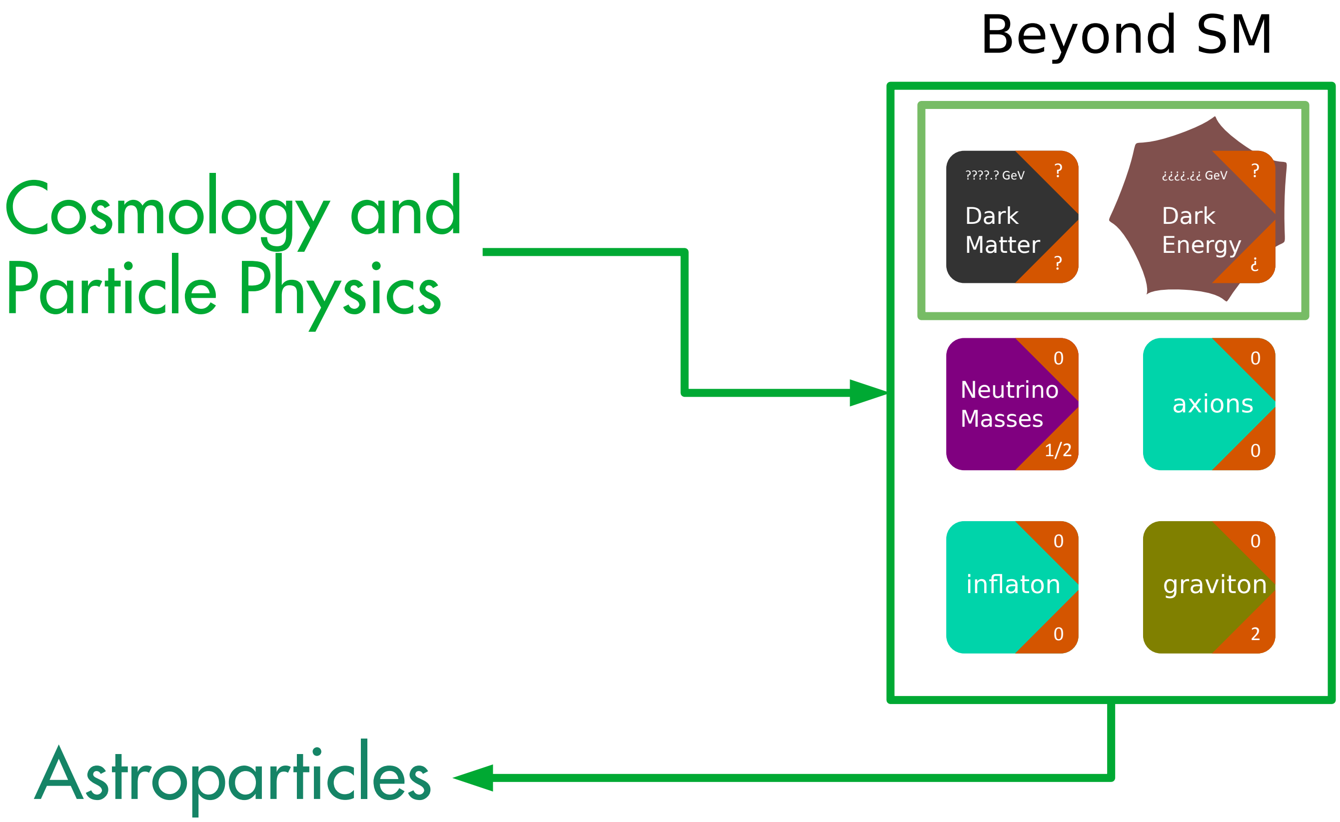


Beyond SM

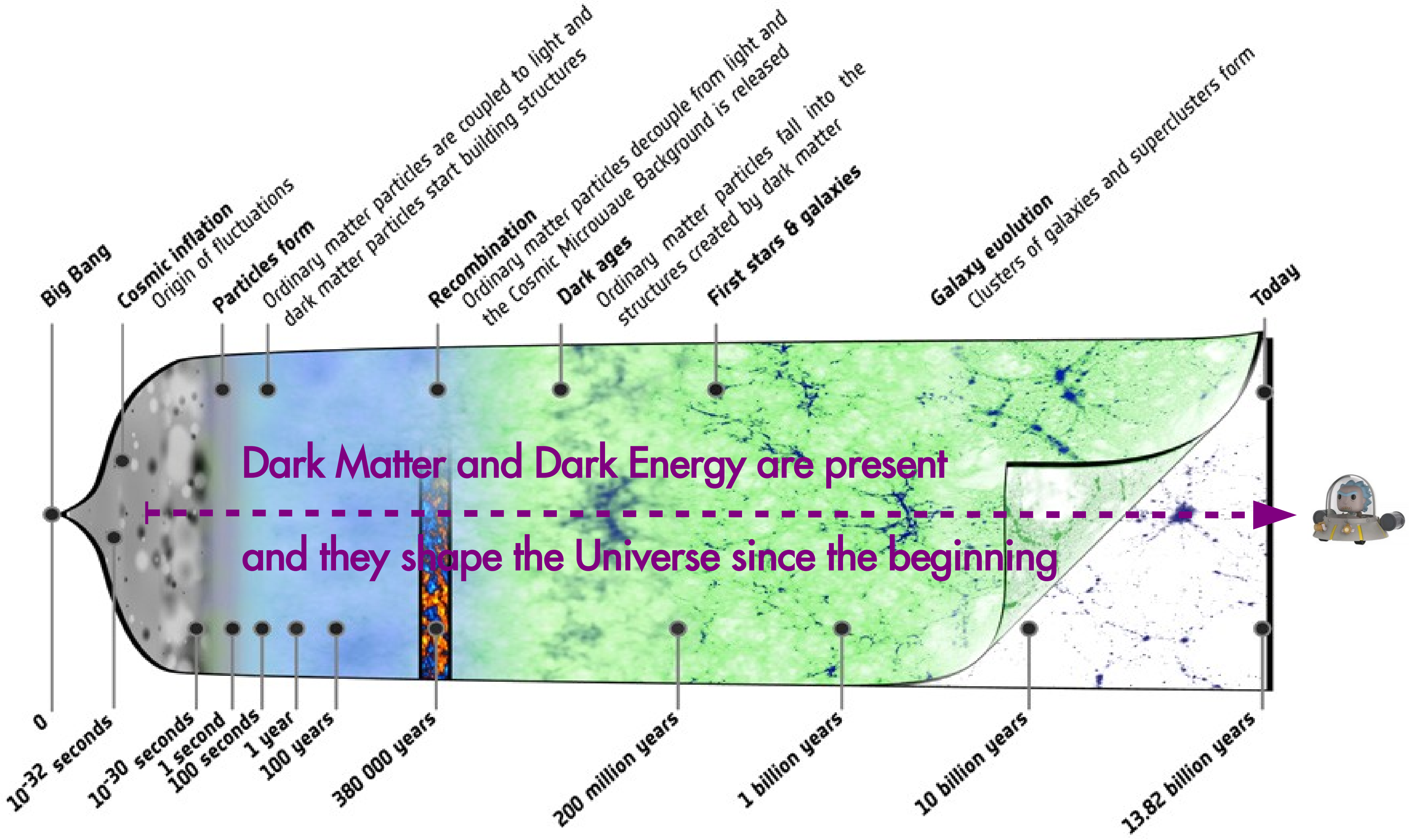


dark matter, neutrino mass,
dark energy, hierarchy ....

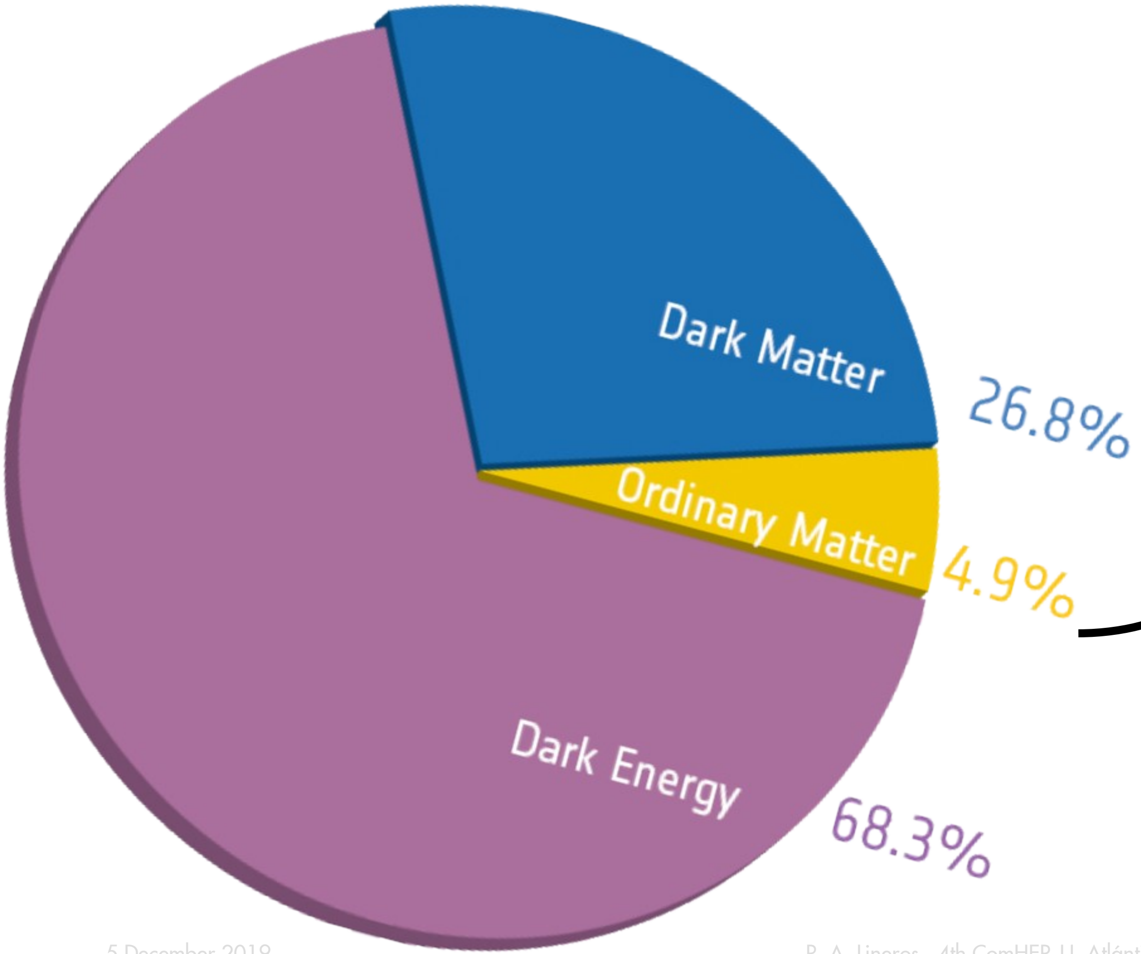
Not everything is explained



The history of our Universe: Cosmological Model

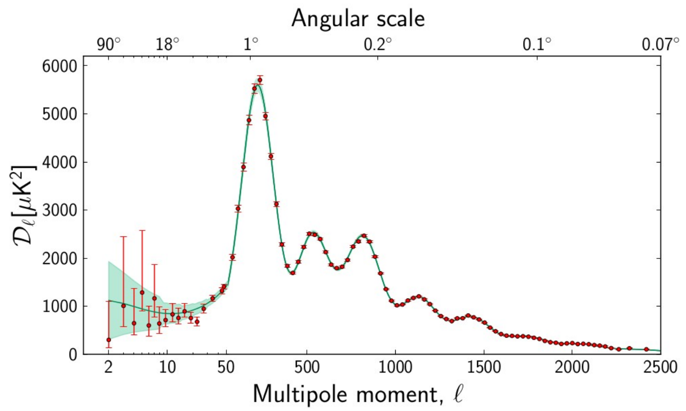


Cosmic Pie



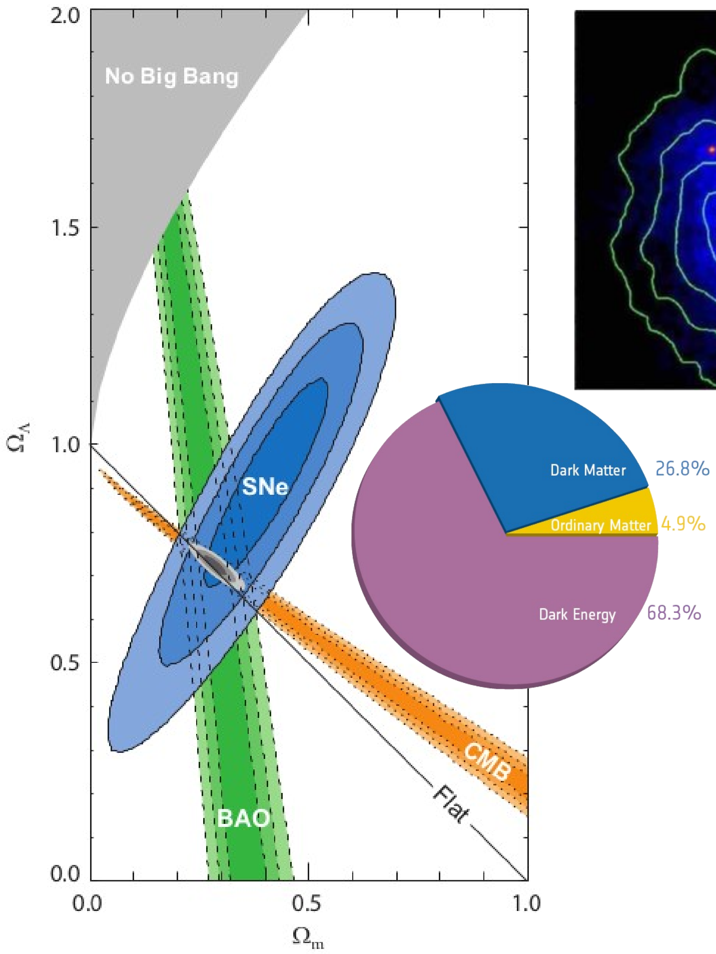
From the matter of the Universe

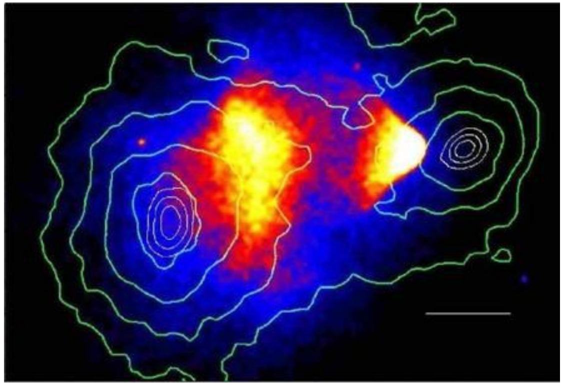
- 15.4% Ordinary Matter
- 84.5% Dark Matter

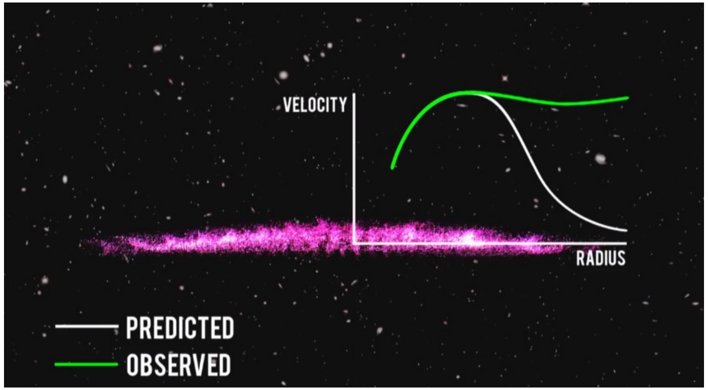


CMB anisotropies helps to unveil them

Dark Matter







Observations support Dark Matter

- Dynamics of clusters and galaxies
- Structure formation
- CMB anisotropies
- Baryon Acoustic Oscillation

$$\Omega_{\rm DM} h^2 = 0.1196 \pm 0.0031$$

Galactic scales

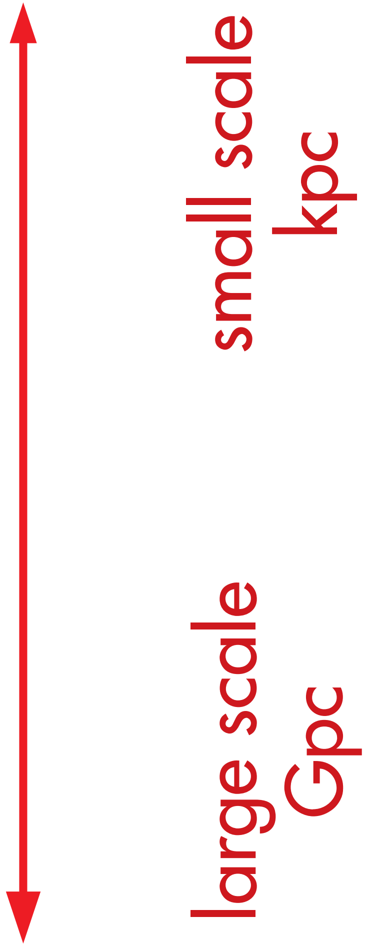
Rotation curve
Weak lensing
Velocity dispersion of satellite galaxies
Velocity dispersion of dSphs

Galaxy cluster scales

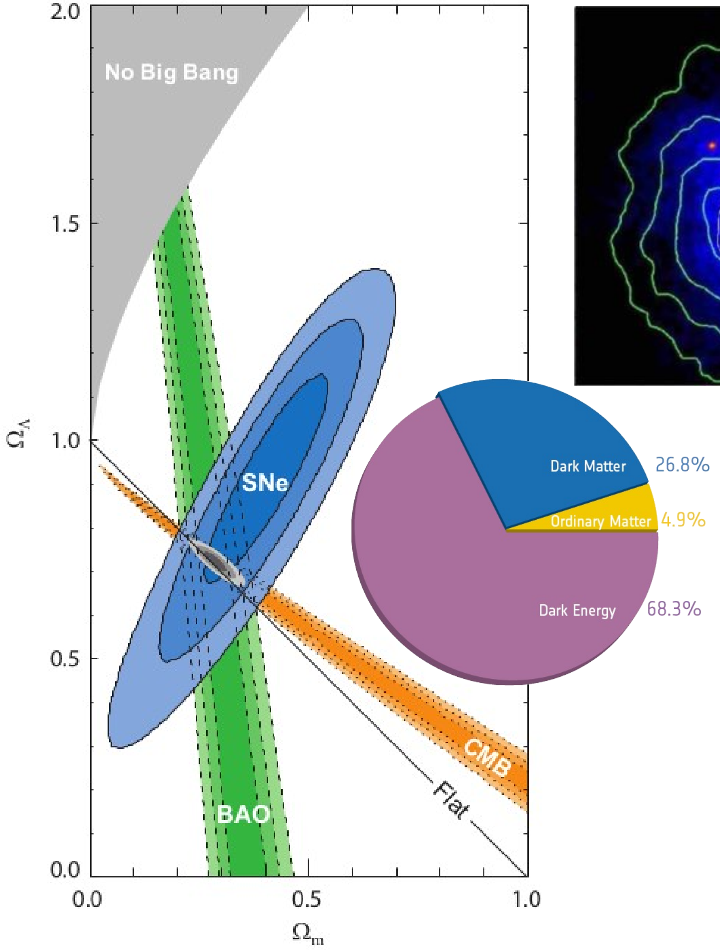
Velocity dispersion of individual galaxies
Strong and weak lensing
Peculiar velocity flows
X-ray emission

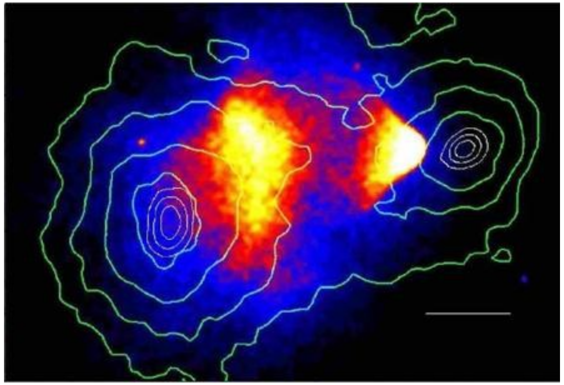
Cosmological scales

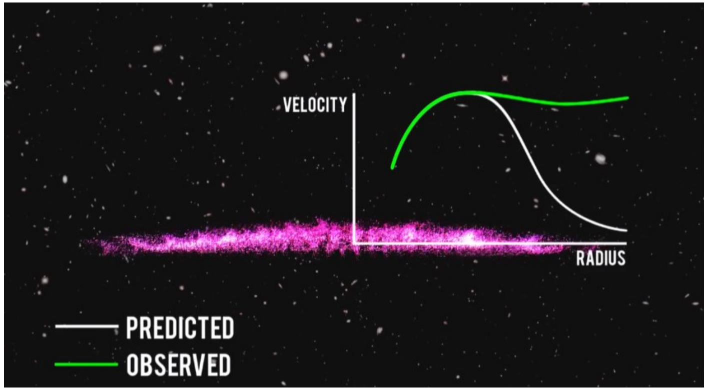
CMB anisotropies
Growth of structure
LSS distribution
BAOs
SZ effect



Dark Matter



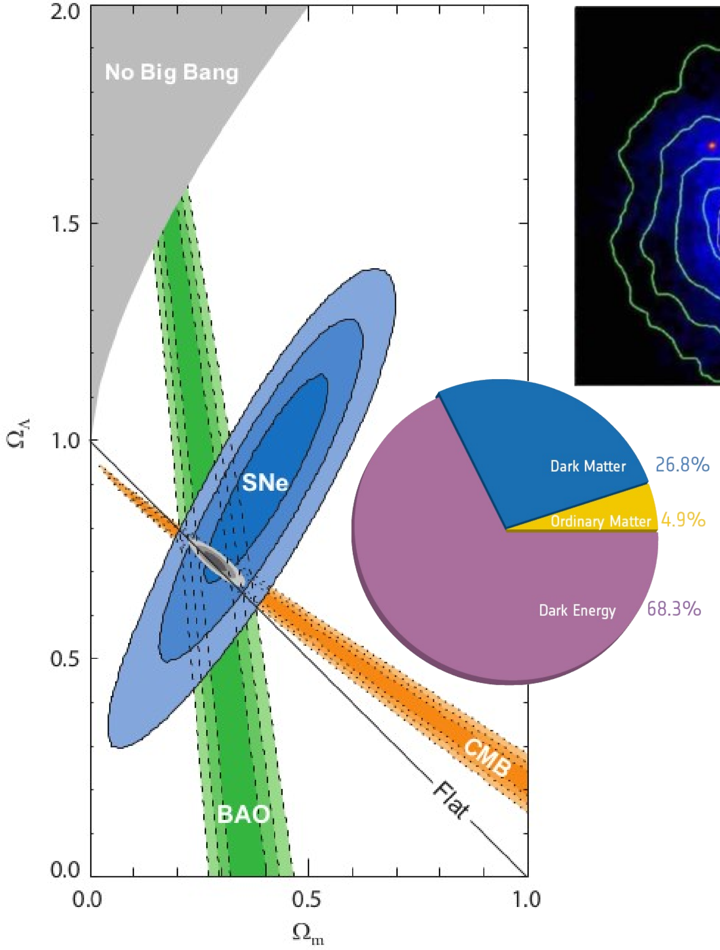


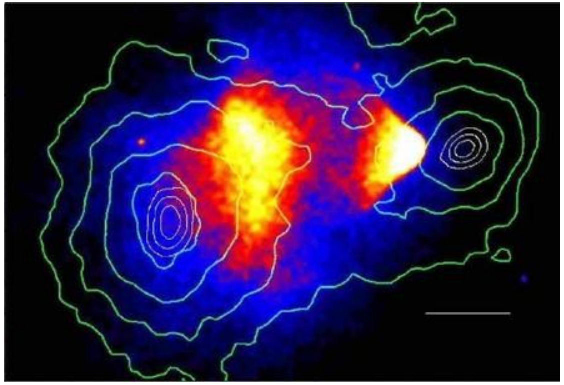


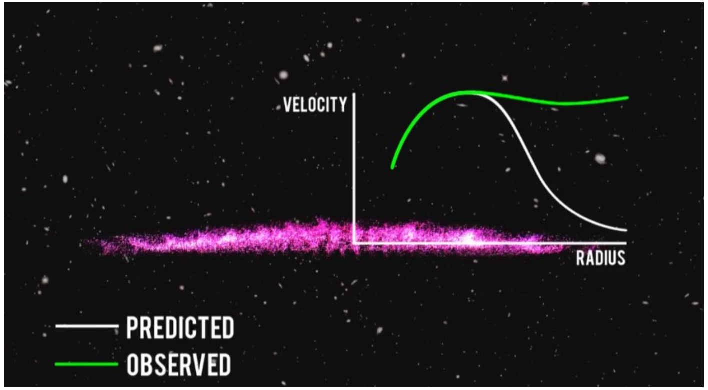
If Dark Matter has a particle origin

- Electrically Neutral
- Massive
- Non Baryonic
- Stable or very long lived
- Weakly interacting

Dark Matter



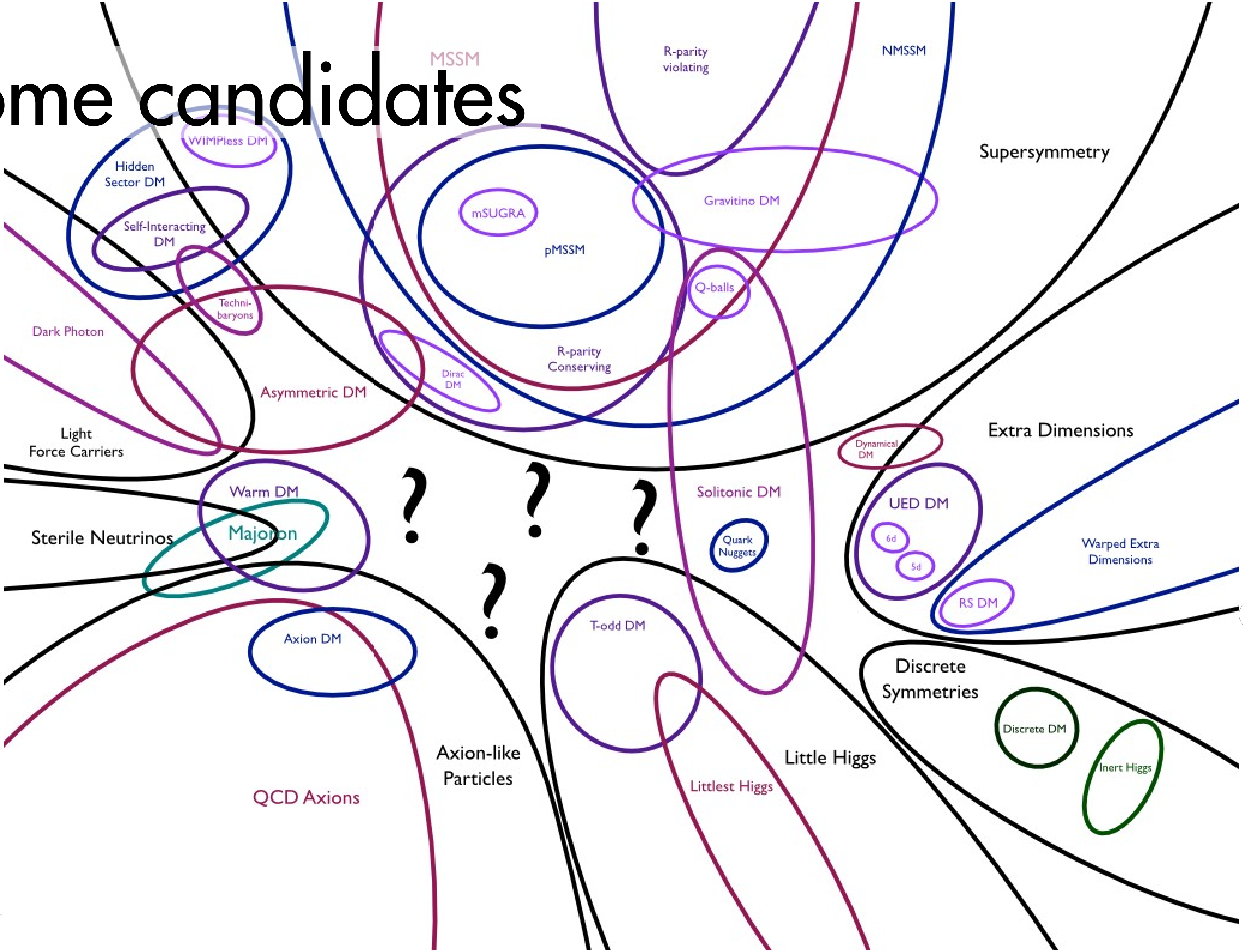


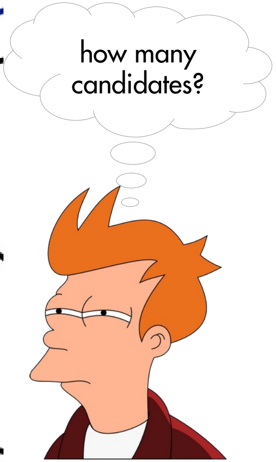


If Dark Matter has a particle origin

- Electrically Neutral
- Massive
- Non Baryonic
- Stable or very long lived
- Weakly interacting

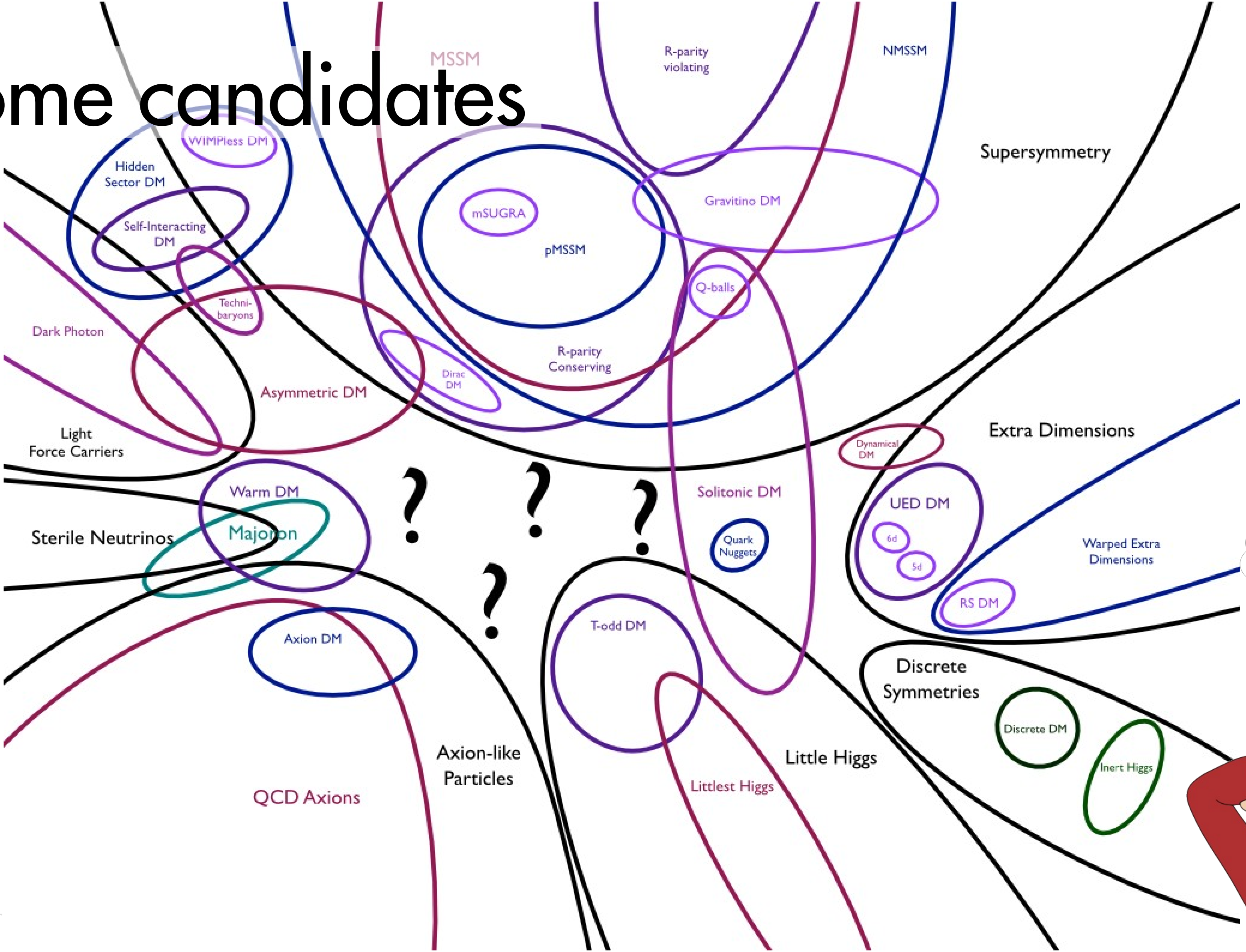
Some candidates

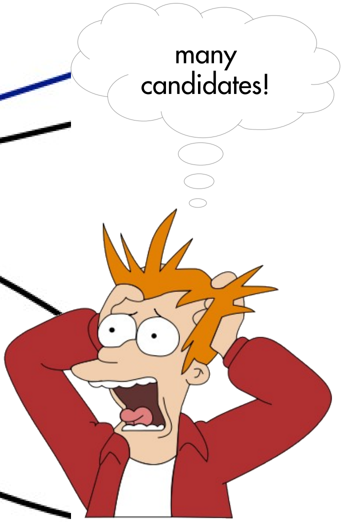




Adapted from 1401.6085

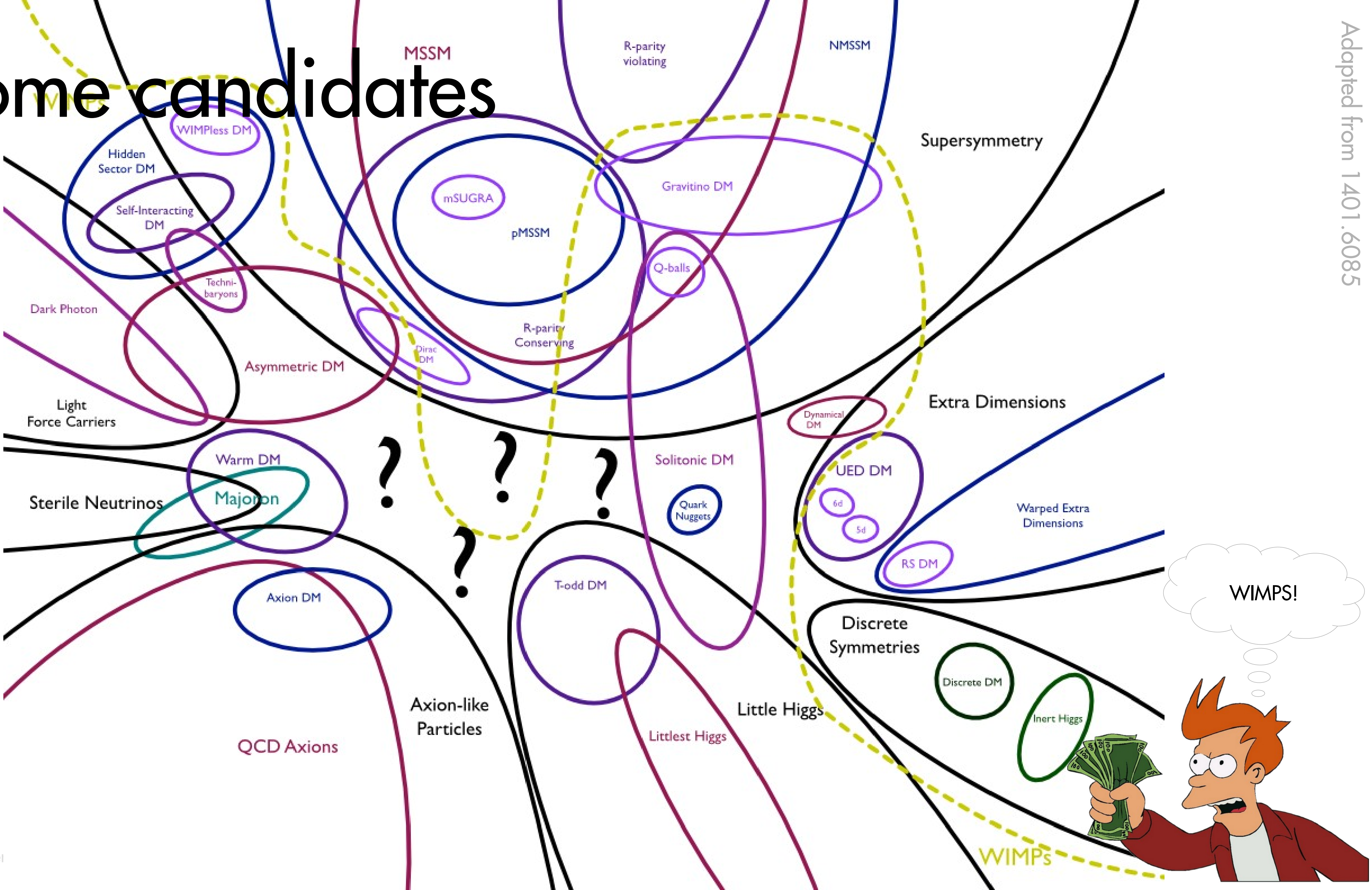
Some candidates





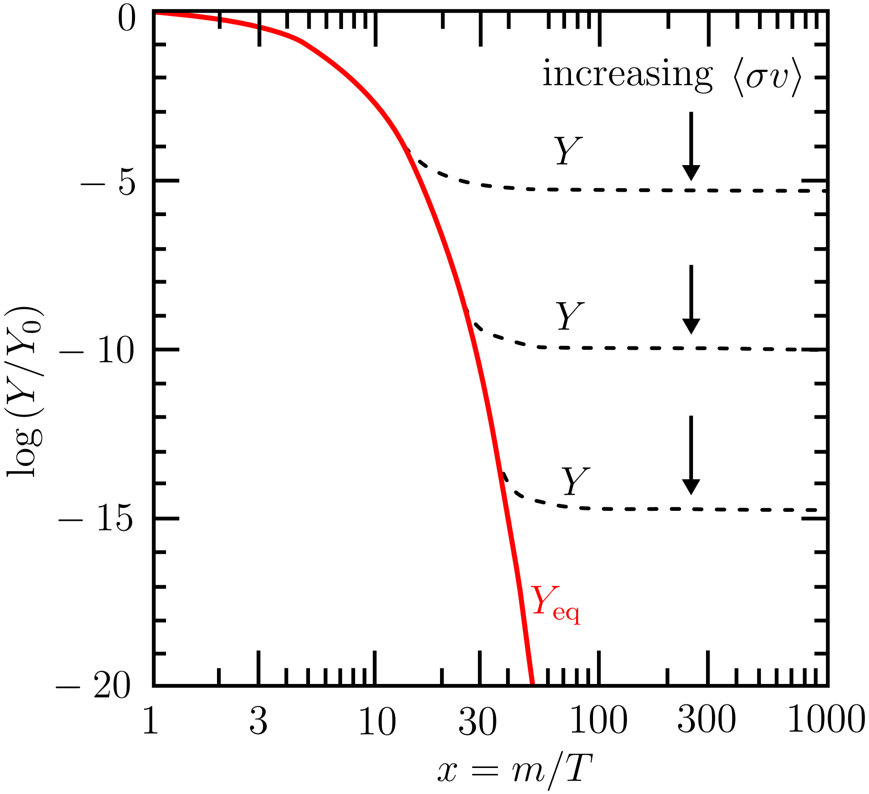
Adapted from 1401.6085

Some candidates



Adapted from 1401.6085

Weakly Interactive Massive Particles



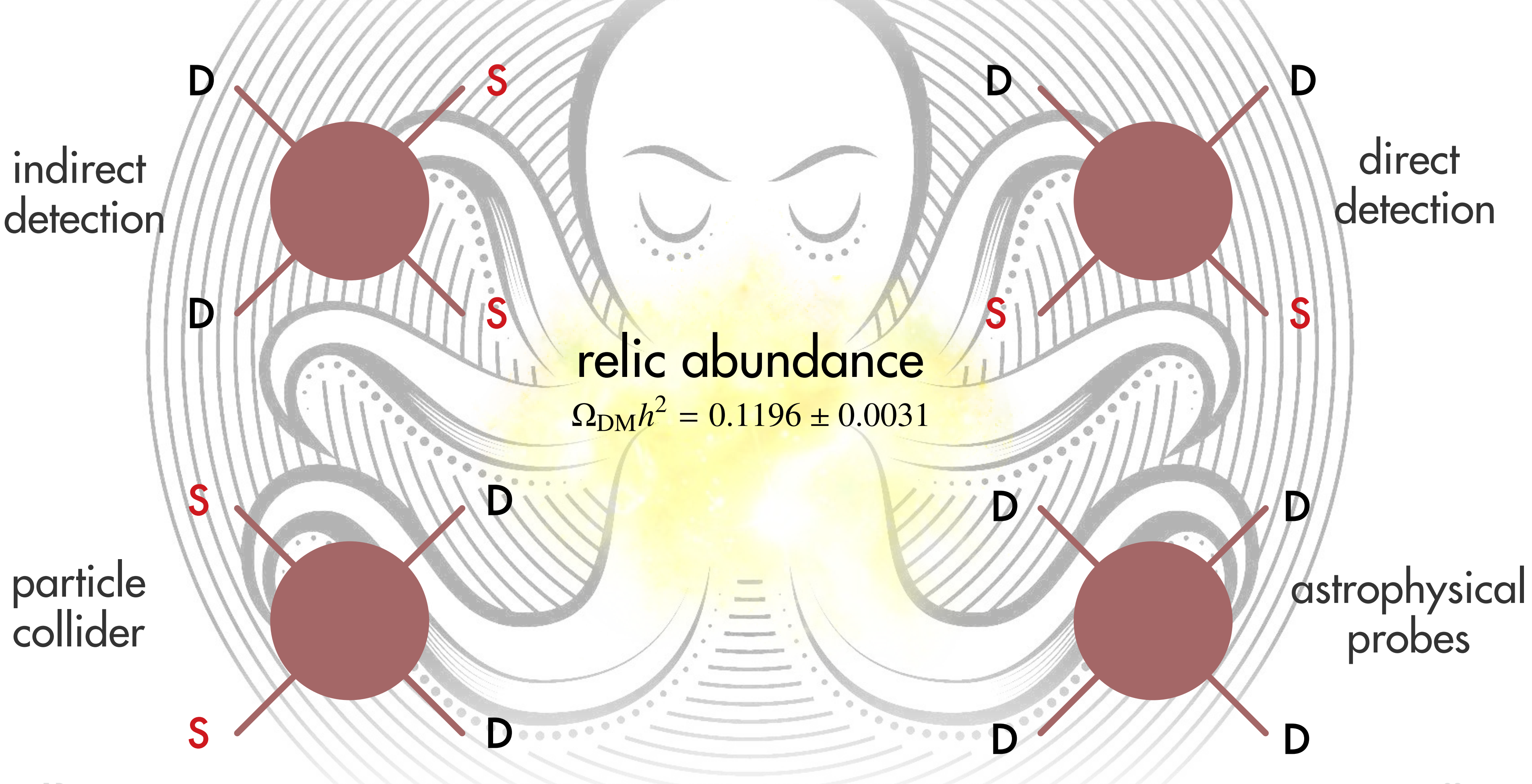
- Big Bang Thermal relic
- Decoupling via Freeze-Out
- Correct relic abundance for

  <σv> ~ 1 pb c

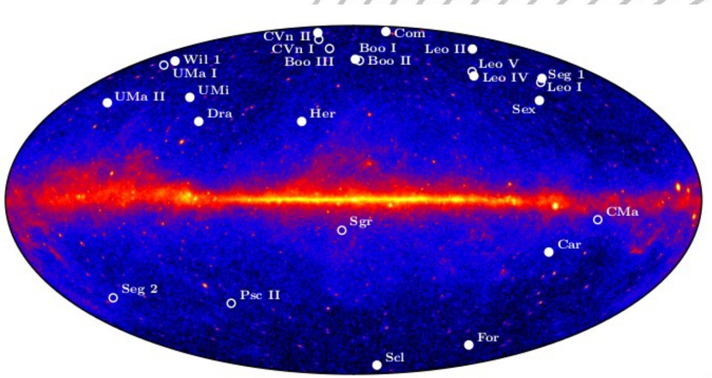
- Mass in GeV-TeV range

For WIMPs: $$\Omega_{DM}h^2 \simeq 0.1 \, \frac{3\times 10^{-26}\,\text{cm}^3/\text{s}}{\langle\sigma v\rangle_{\text{f.o.}}}$$ $$T^{\text{f.o.}}_{\text{DM}} \simeq \frac{1}{20} m_{\text{DM}}$$

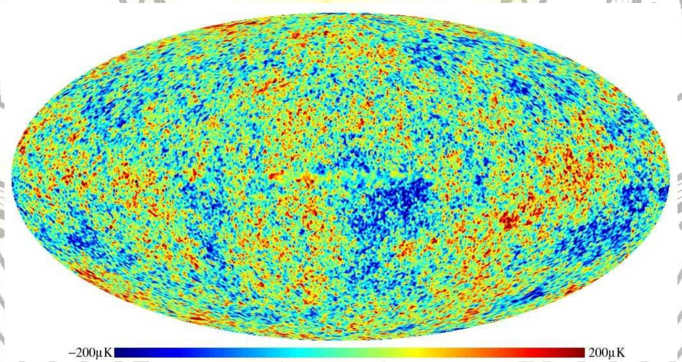
Dark Matter Searches



Dark Matter Searches



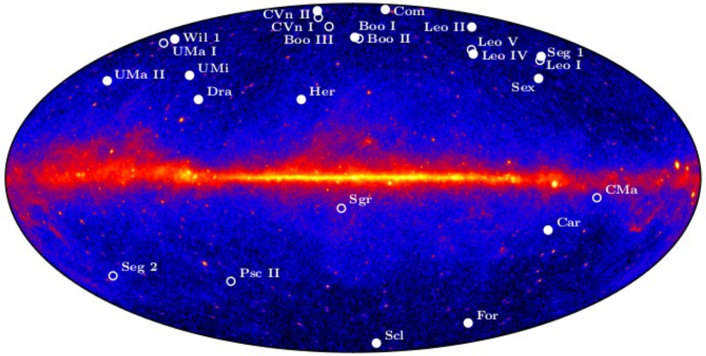
D

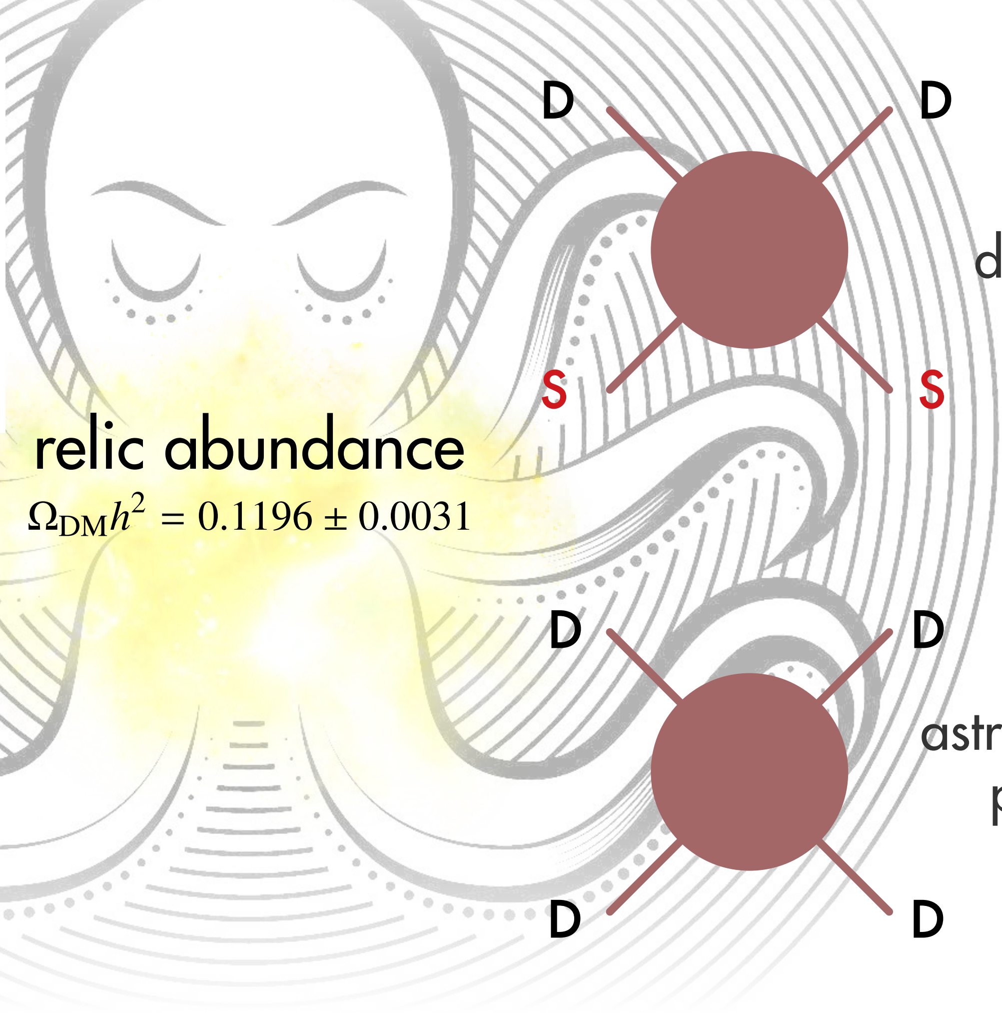


D

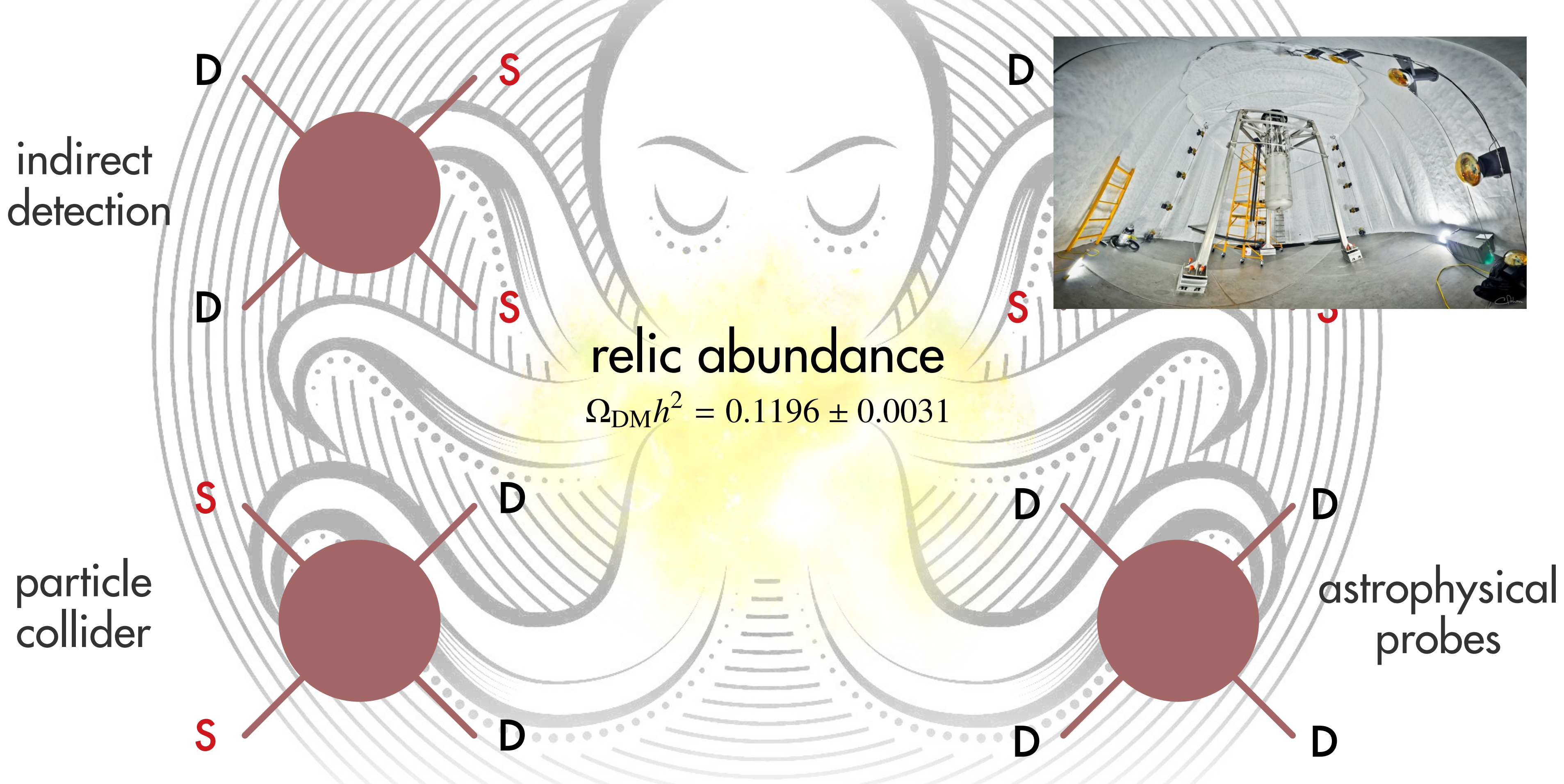
D

Dark Matter Searches

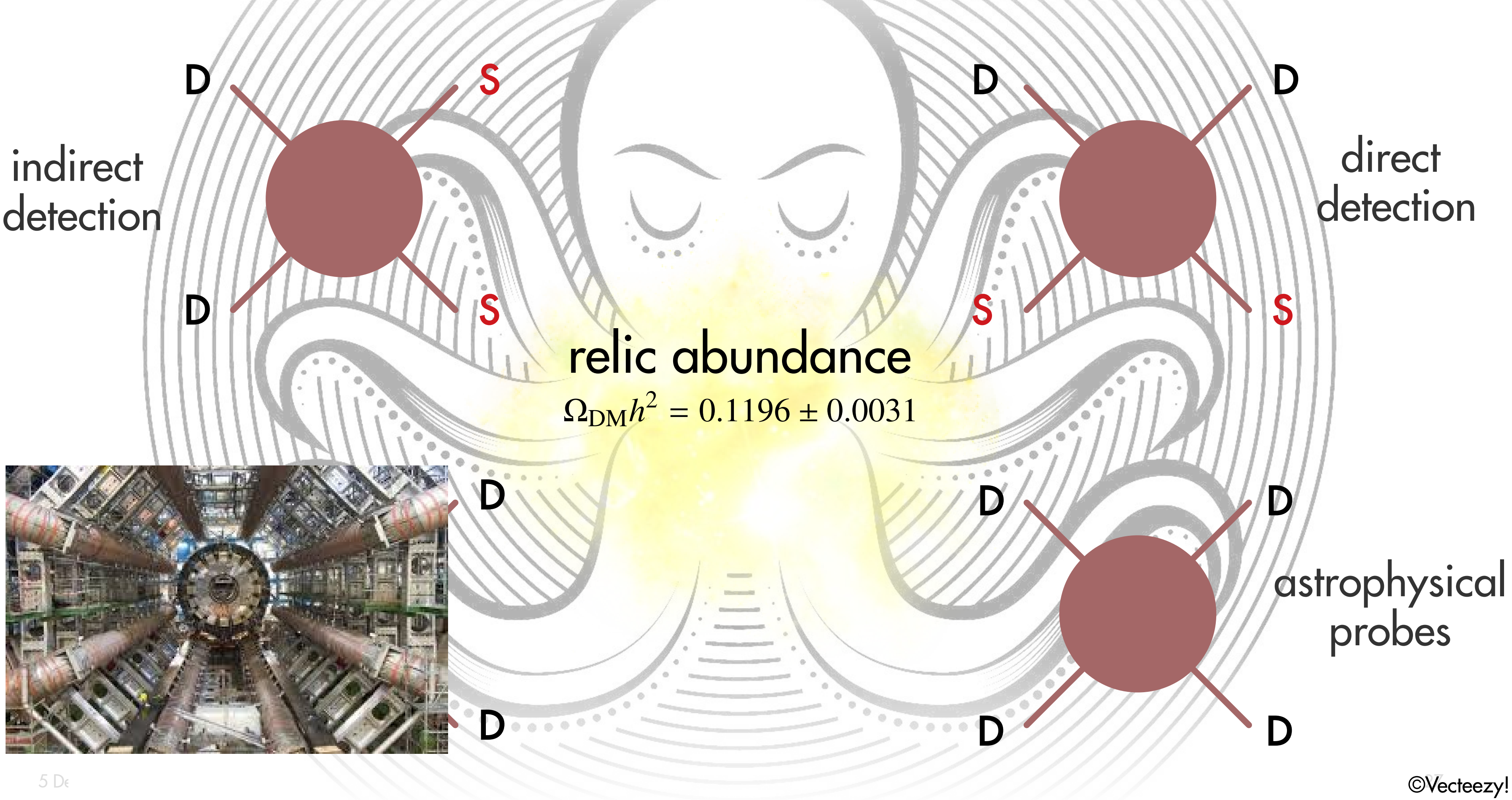




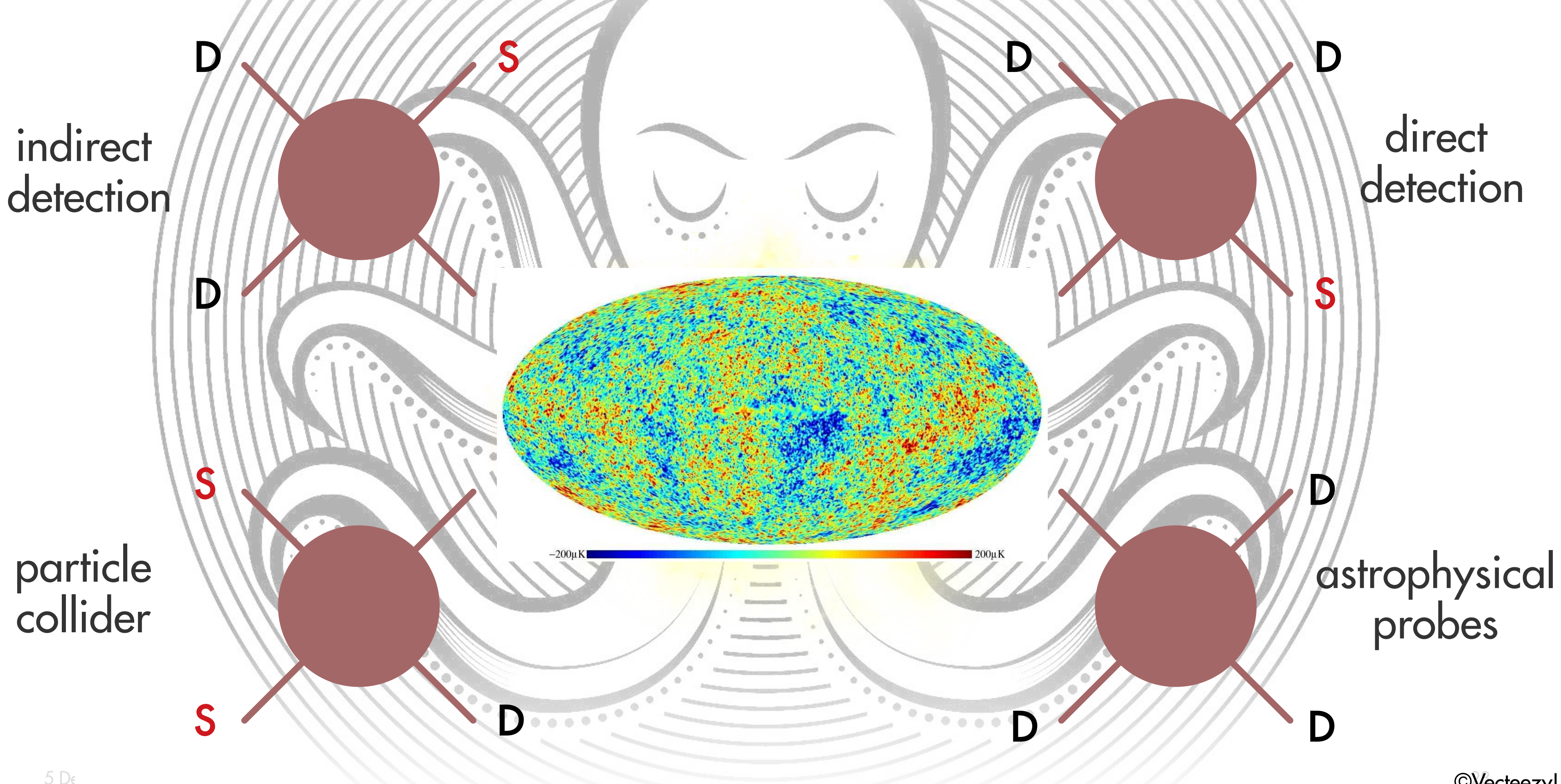
Dark Matter Searches



Dark Matter Searches

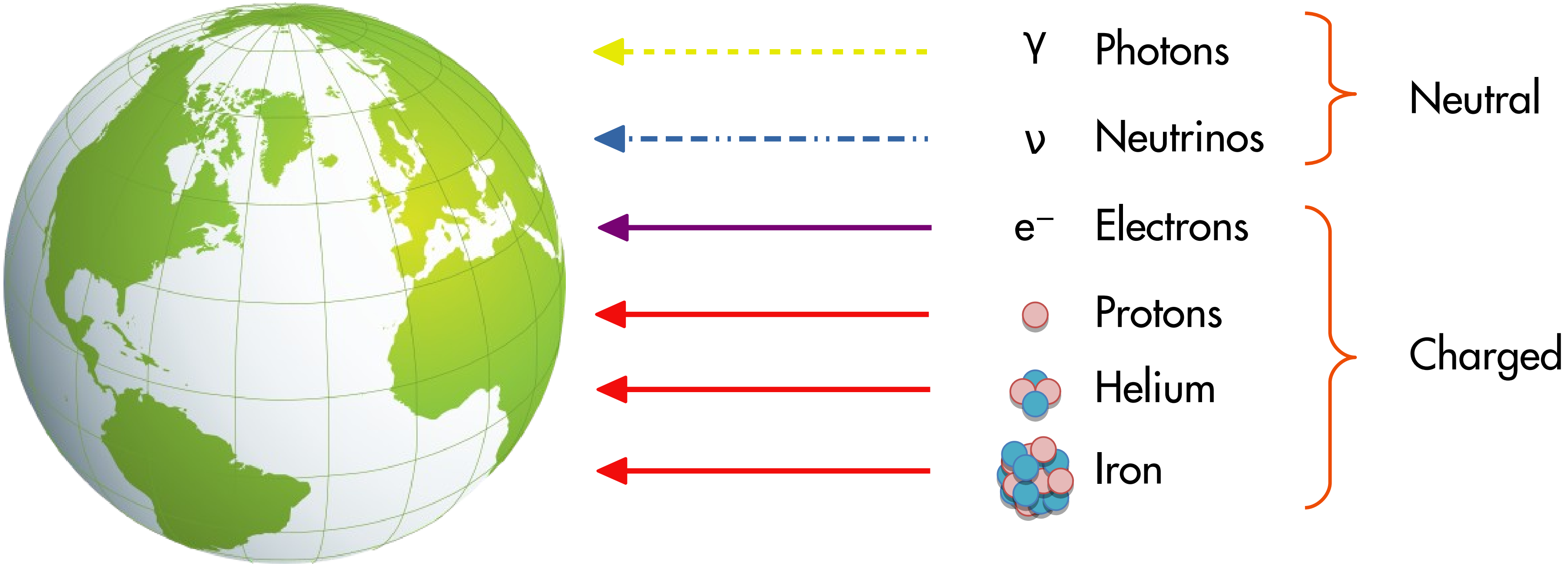


Dark Matter Searches



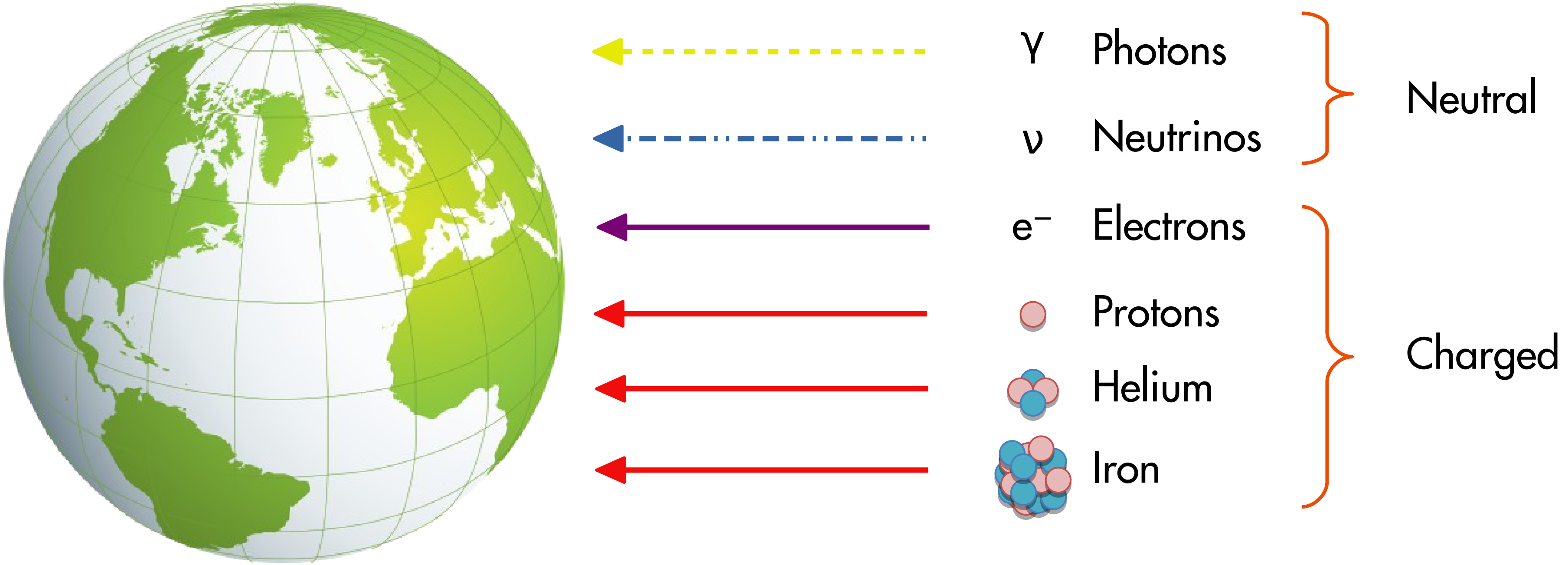
Astroparticle searches of Dark Matter

Particles from outer space



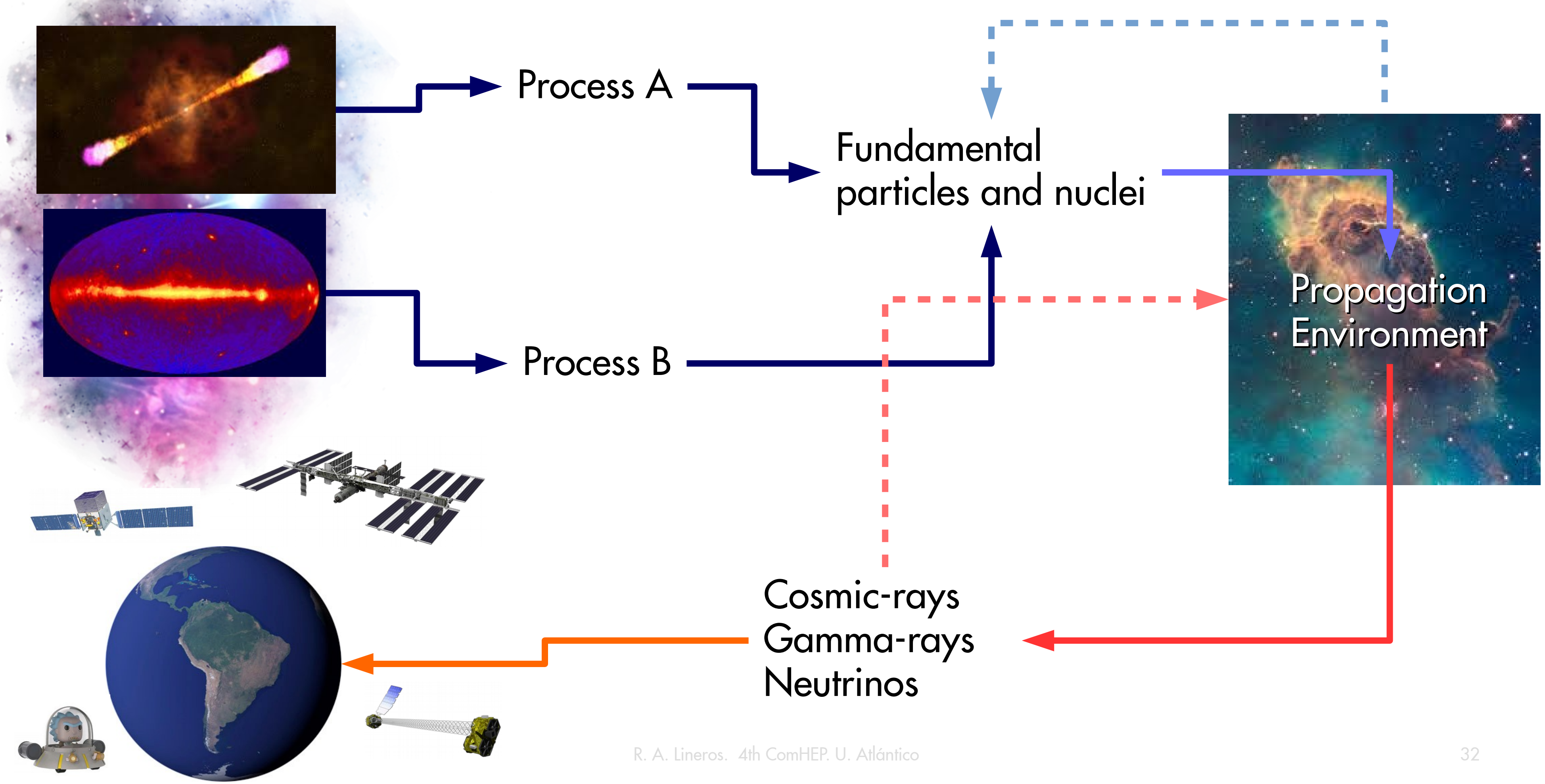
Notice that each type of particles propagate differently

Particles from outer space

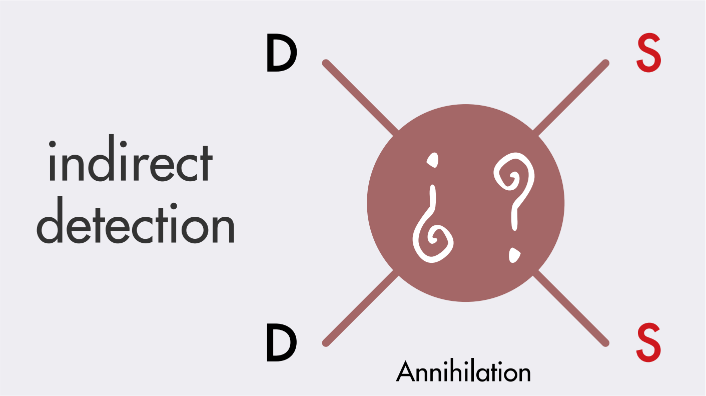


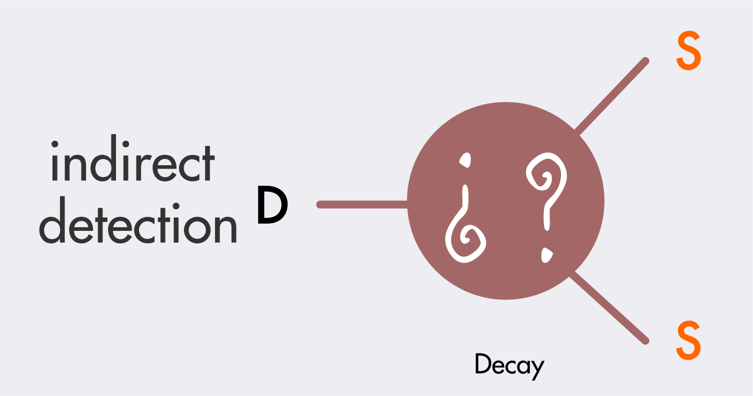
All of these astroparticles help us to study:
sources, interstellar medium, (extra) galactic magnetic fields, etc.

Multimessengers



Dark Matter as Source

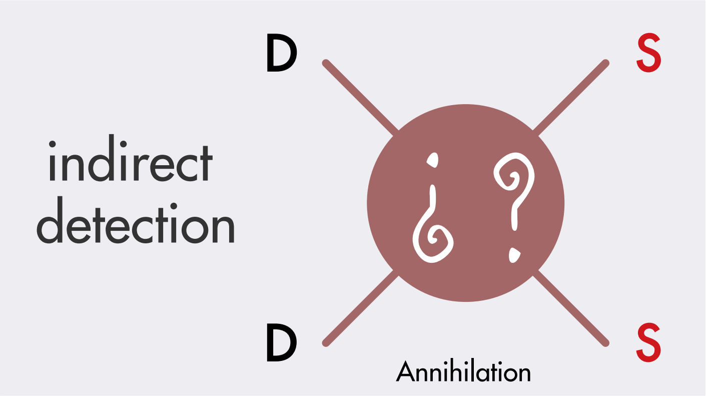


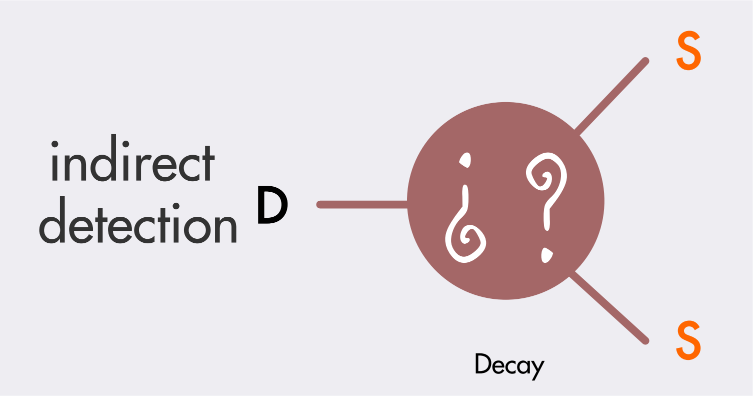


The production of SM particles from DM are excellent examples to learn about astroparticles

Indeed, the DM search with astroparticles has been one of the main driving force of the field!

Dark Matter as Source





Astroparticle's transport equation

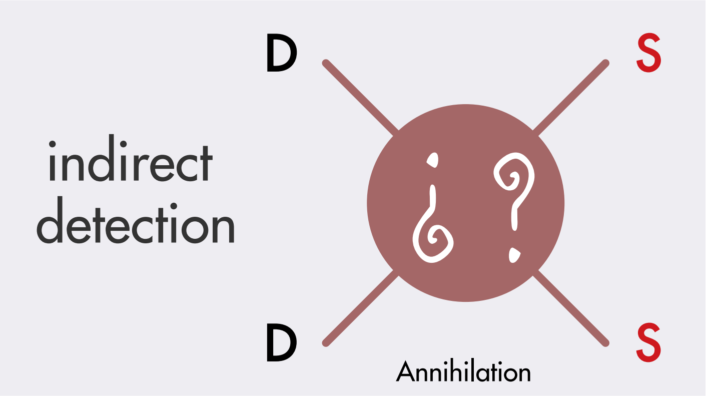
- Photons and neutrinos straight line propagation
- Cosmic rays diffusive propagation

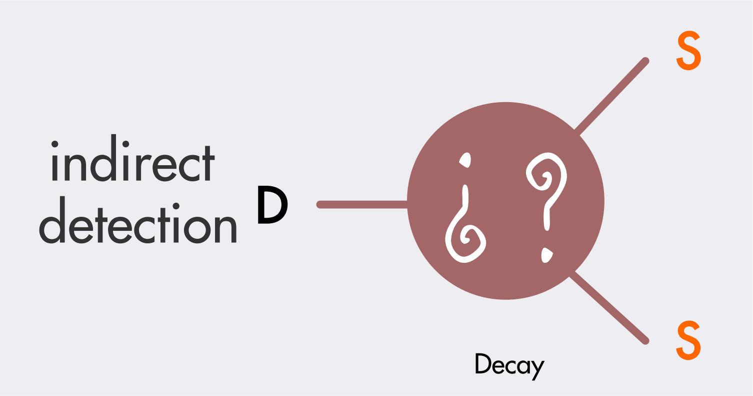
$$\frac{D\Psi}{Dt} = s$$

Source term due to

- Dark Matter
- Astrophysical source
- Astroparticle interactions

Dark Matter as Source





Depending of the way how DM produces SM particles, the source term follows:

$$s_{\rm DM}(\vec{x},\epsilon) = \eta \, \langle \sigma v \rangle \, \frac{\rho^2_{\rm DM}(\vec{x})}{m^2_{\rm DM}} \, \frac{dn_X}{d\epsilon}(\epsilon)$$

Annihilation

$$s_{\rm DM}(\vec{x},\epsilon) = \frac{1}{\tau_{\rm DM}} \, \frac{\rho_{\rm DM}(\vec{x})}{m_{\rm DM}} \, \frac{dn_X}{d\epsilon}(\epsilon)$$

Decay

Dark Matter as Source

Annihilation cross section

Production spectrum

$$s_{\rm DM}(\vec{x}, \epsilon) = \eta \left\langle \sigma v \right\rangle \frac{\rho^2_{\rm DM}(\vec{x})}{m^2_{\rm DM}} \frac{dn_X}{d\epsilon}(\epsilon)$$

Number density

Dark Matter as Source

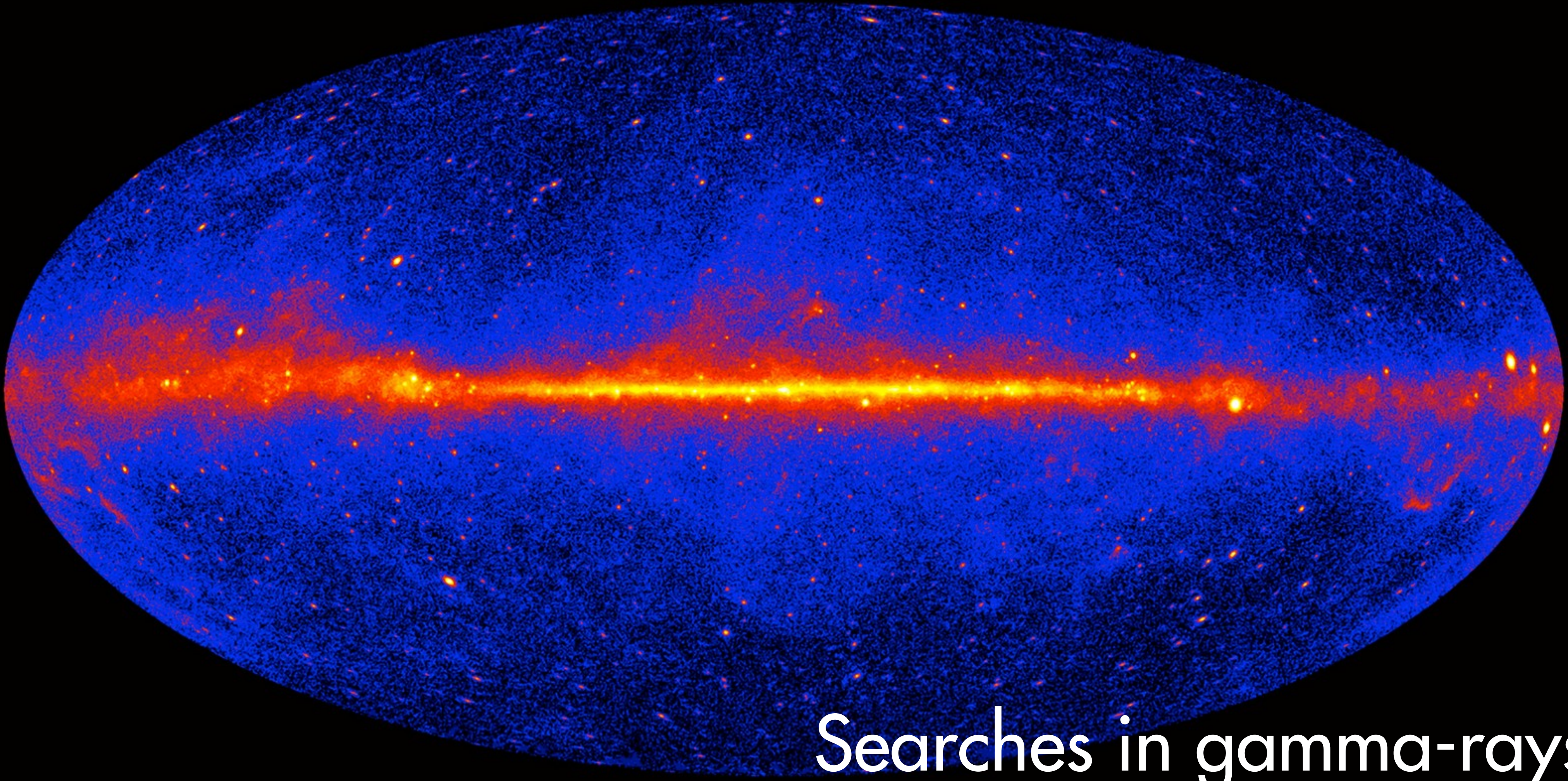
Particle physics/Cosmology

Particle physics

$$s_{\mathrm{DM}}(\vec{x},\epsilon) = \eta \,\langle \sigma v \rangle \,\frac{\rho^2_{\mathrm{DM}}(\vec{x})}{m^2_{\mathrm{DM}}}\,\frac{dn_X}{d\epsilon}(\epsilon)$$

Particle Physics/Cosmology

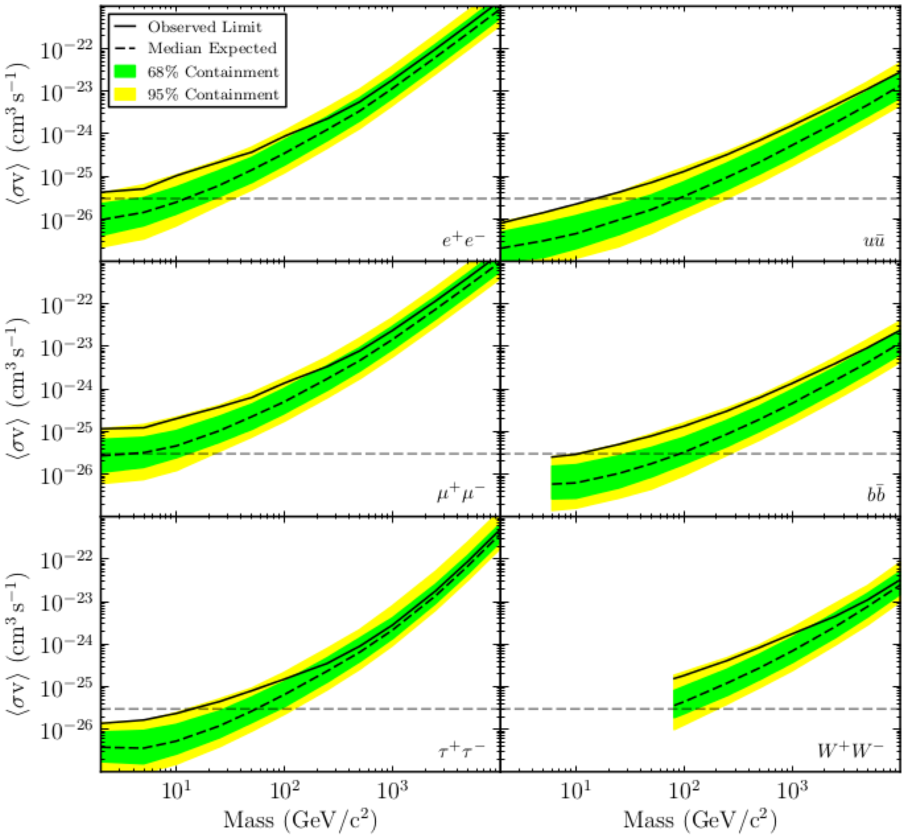
FERMI-LAT Gamma-ray sky

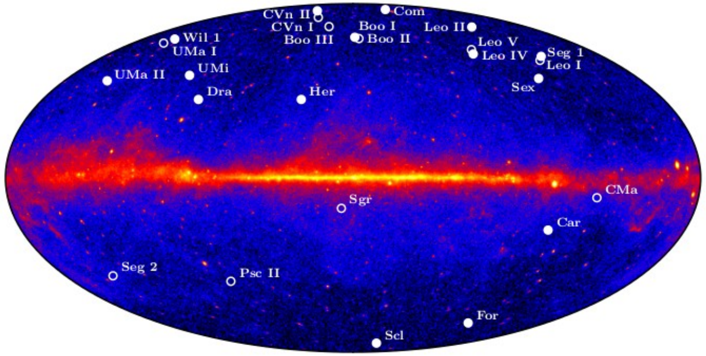


Searches in gamma-rays

Searches in gamma rays (Dwarf Spheroidal Galaxies)

Fermi-LAT Collaboration. arXiv:1310.0828



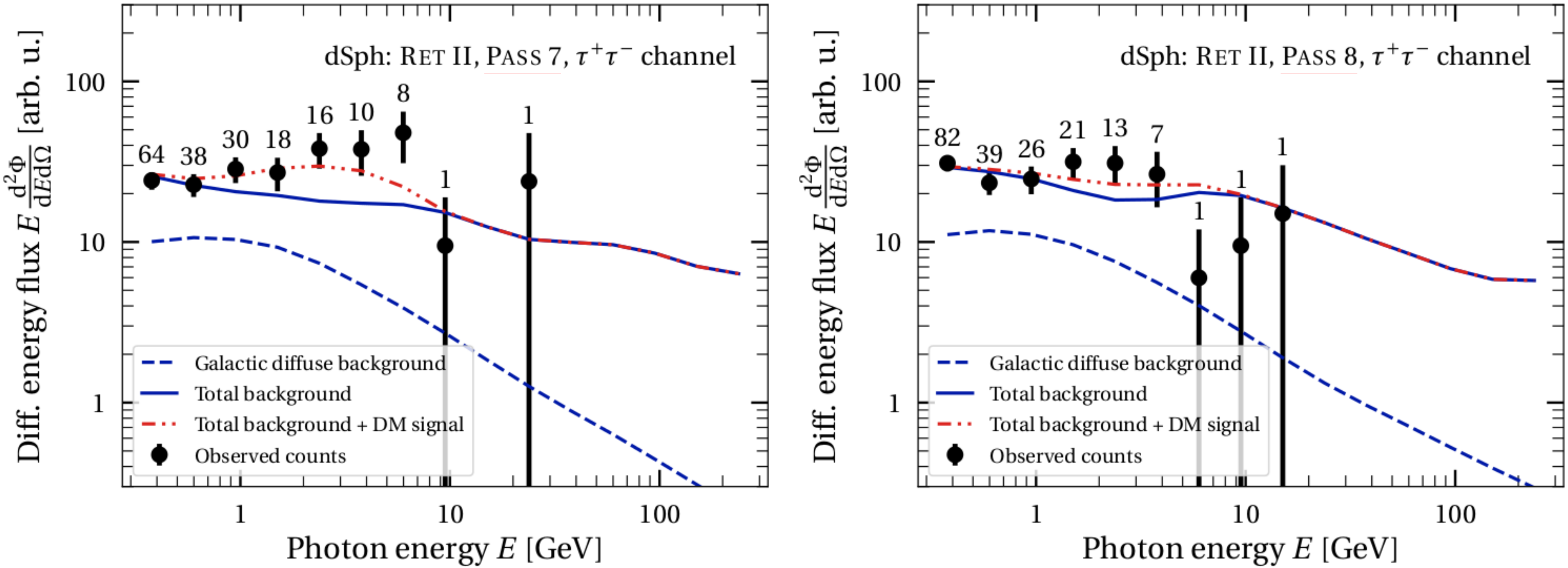


Combined analysis on 25+ Dwarf Spheroidal Galaxies

dSph are good target due to low astrophysical background.

Searches in gamma rays (Dwarf Spheroidal Galaxies)

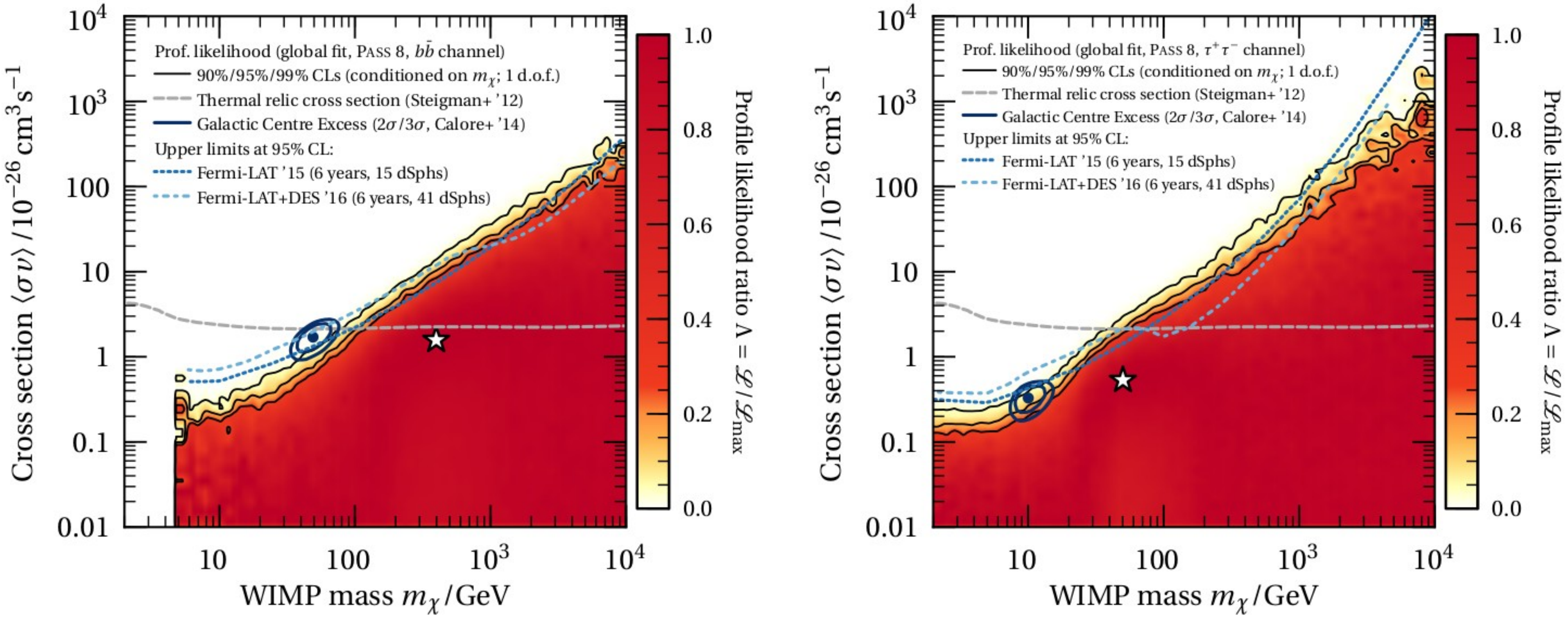
S. Hoff et al. arxiv:1812.06986



Among the dSph galaxies Reticulum II is the one with better prospects for analysis

Searches in gamma rays (Dwarf Spheroidal Galaxies)

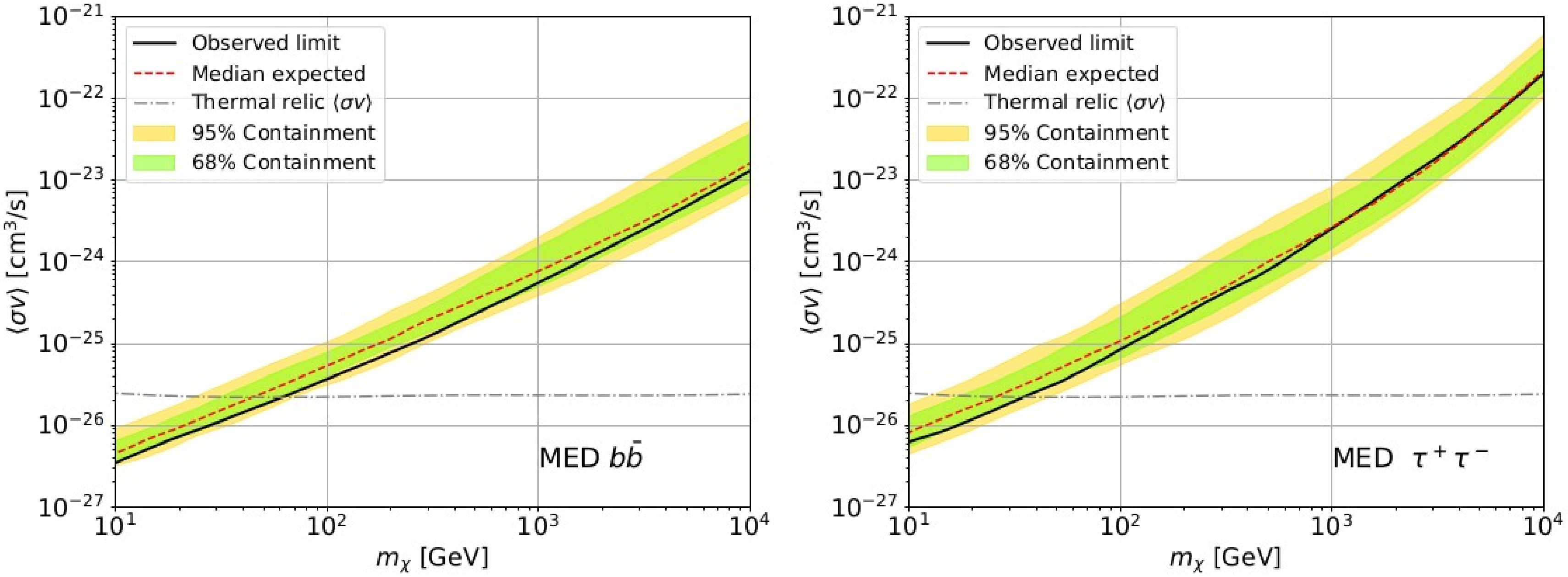
S. Hoff et al. arxiv:1812.06986



Among the dSph galaxies Reticulum II is the one with better prospects for analysis

Searches in gamma rays (M31 and M33 galaxies)

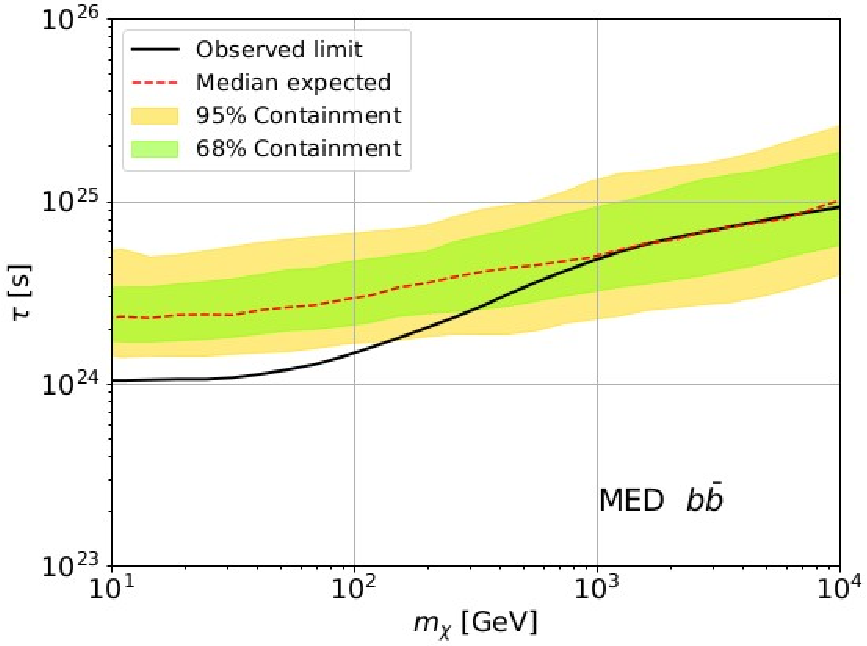
Di Mauro et al. arxiv:1904.10977

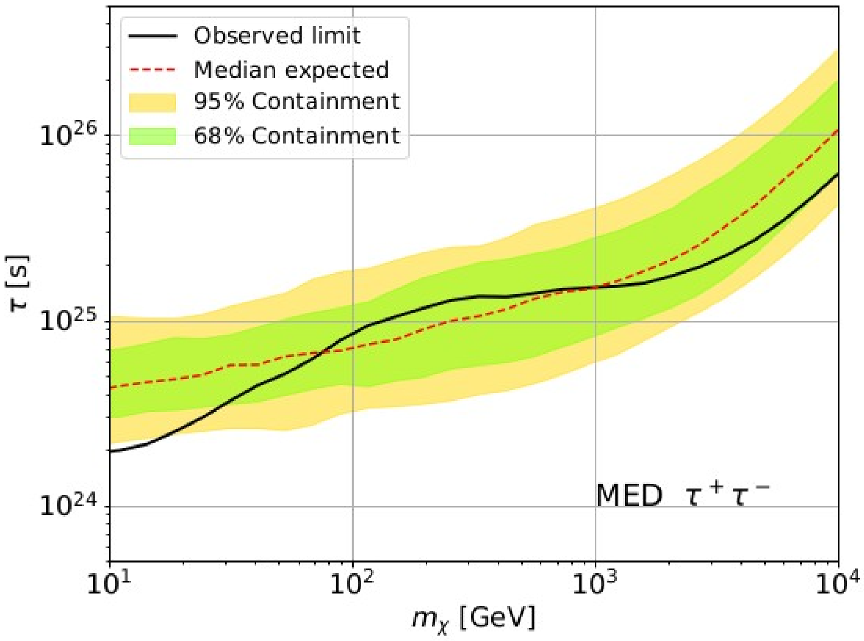


Andromeda and Triangulum galaxies are good target to search for DM in gamma-rays

Searches in gamma rays (M31 and M33 galaxies)

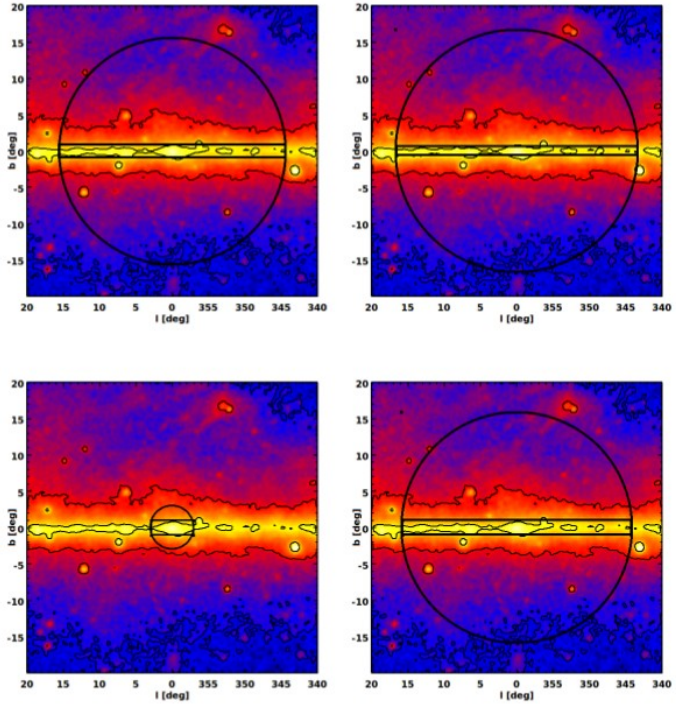
Di Mauro et al. arxiv:1904.10977

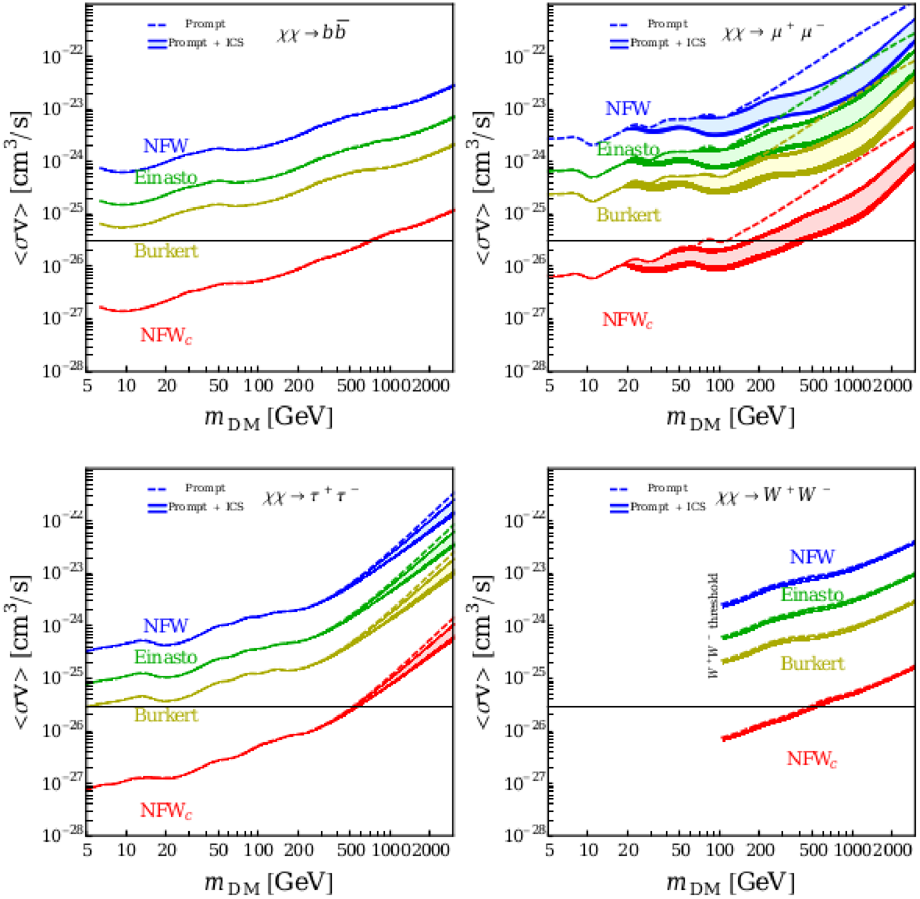




And also to constrain Decaying DM escenario

Searches in gamma rays (Galactic Center)

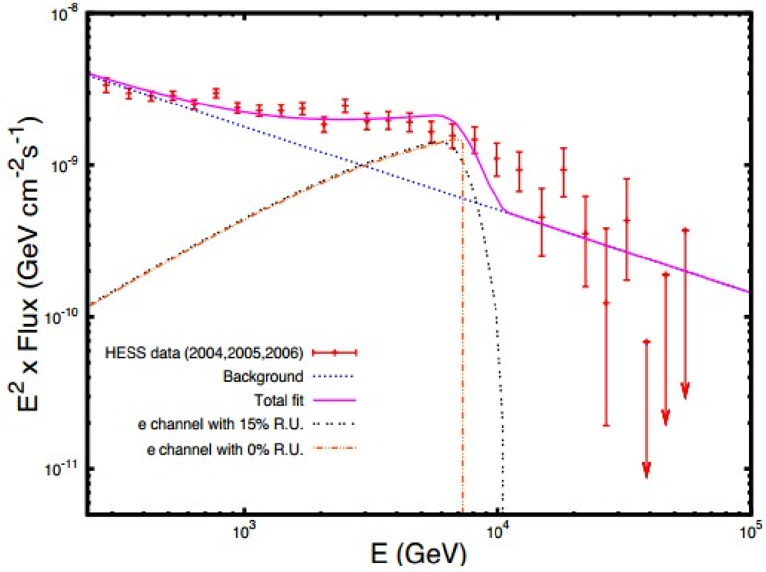


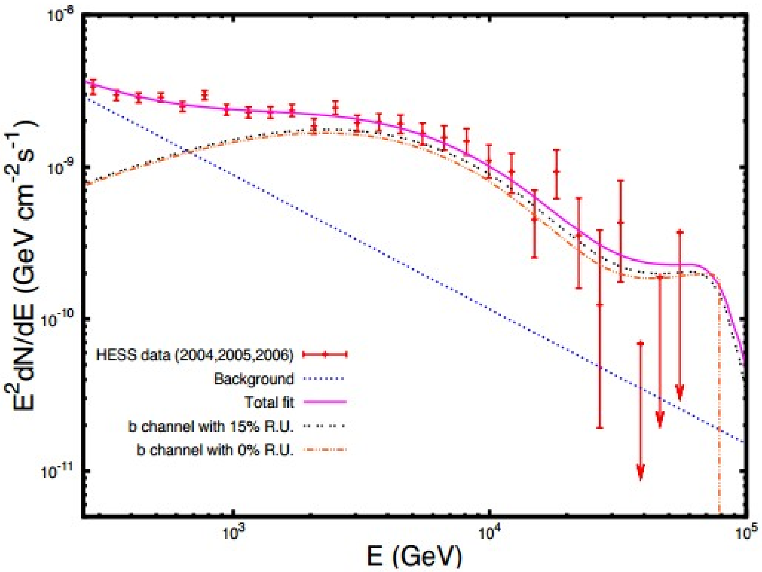


G. Gómez-Vargas et al.
JCAP10(2013)029. arXiv:1308.3515

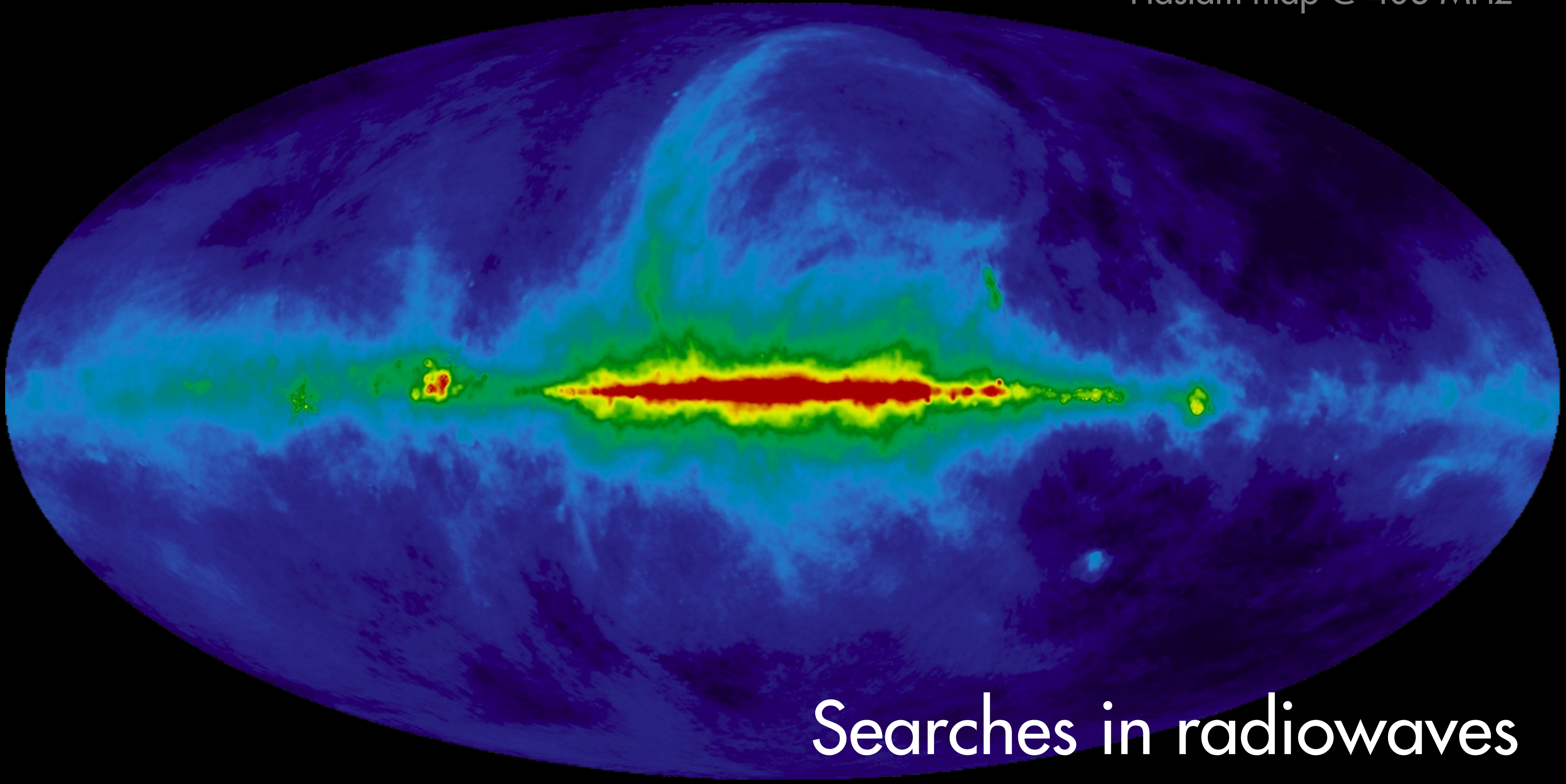
Searches in gamma rays (Galactic Center)

Cembranos et al. arXiv:1302.6871



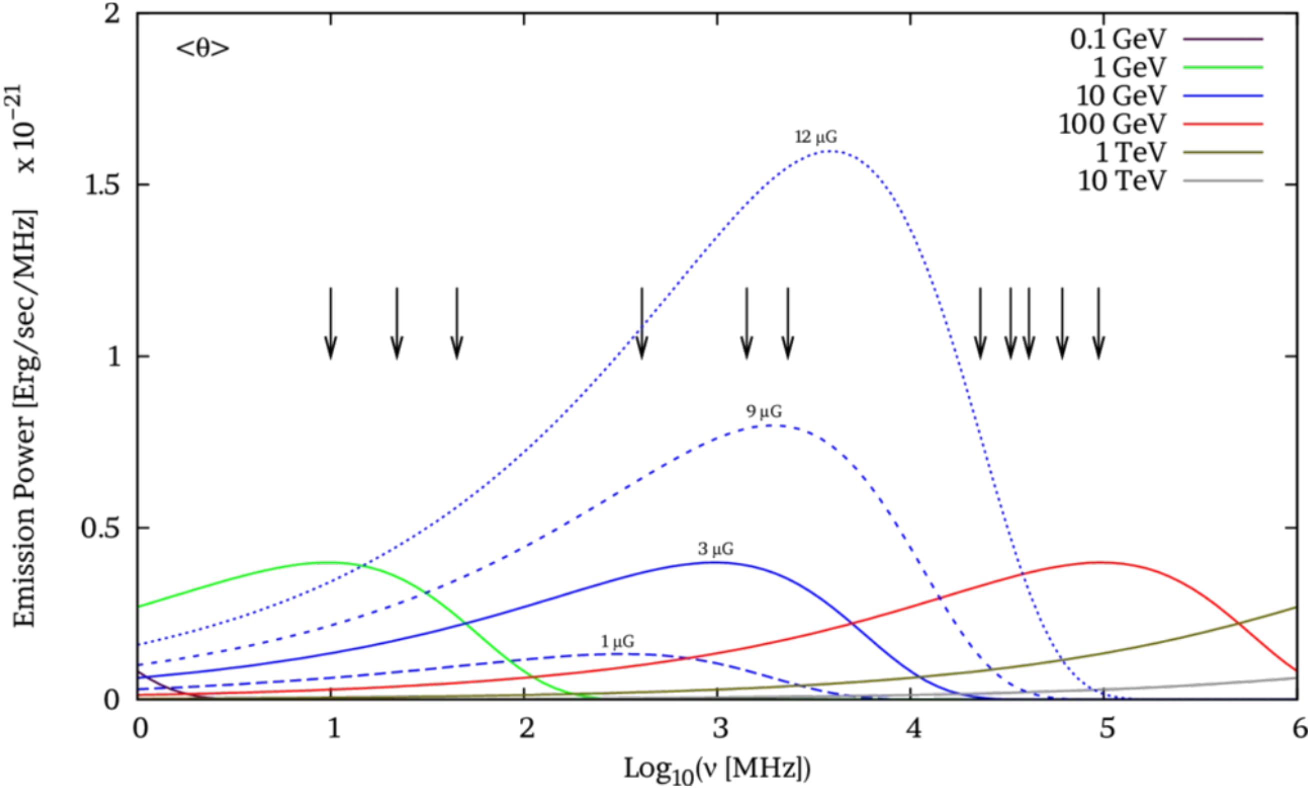


Observation done with HESS indicate a signal compatible with DM at the TeV range



Searches in radiowaves

Synchrotron radiation



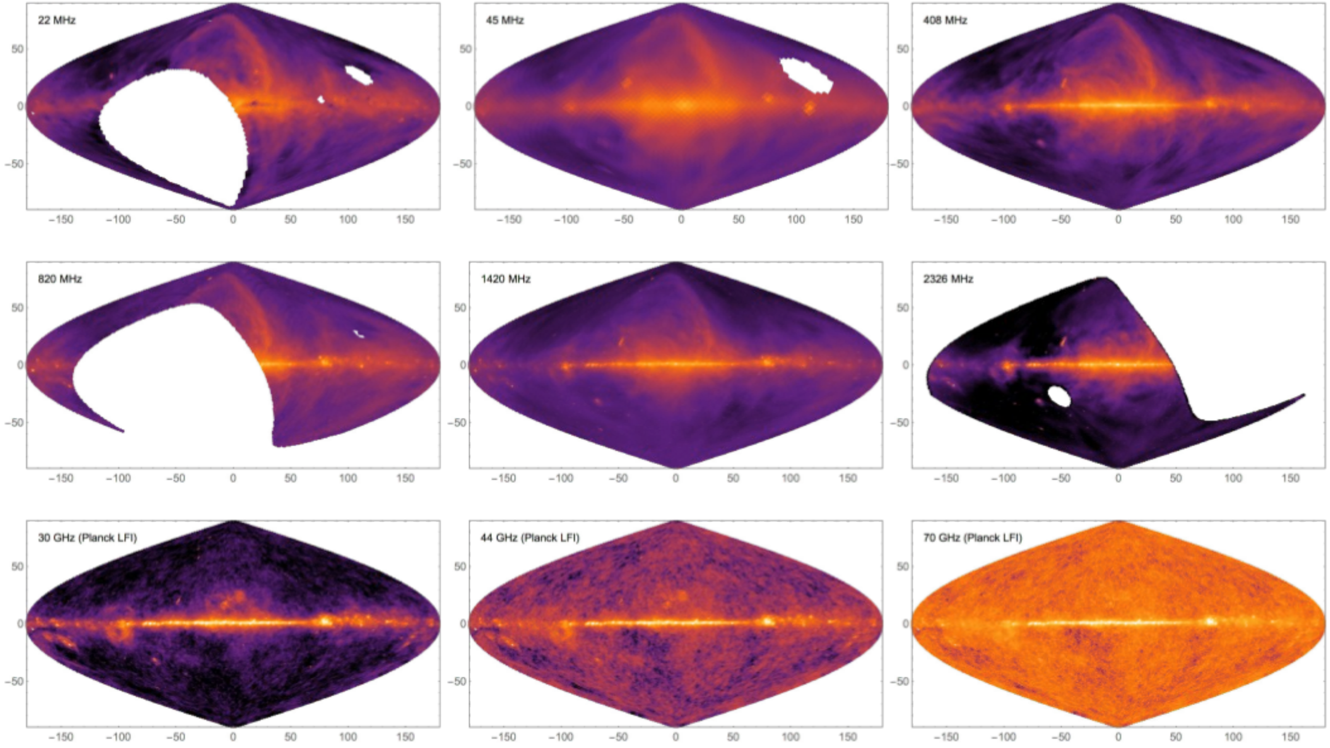
$$\frac{dw}{d\nu}(\nu, B_\perp) = \frac{\sqrt{3}\, e^3 B_\perp}{m_e c^2} F\left(\frac{\nu}{\nu_{c,\perp}}\right)$$

$$\nu_{c,\perp} = \frac{3eB_\perp E^2}{4\pi m_e^3 c^5}$$

$$F(x) = x \int_x^\infty d\zeta \; K_{5/3}(\zeta)$$

Galactic DM radio emission

Cirelli et al.
arxiv: 1604.06267

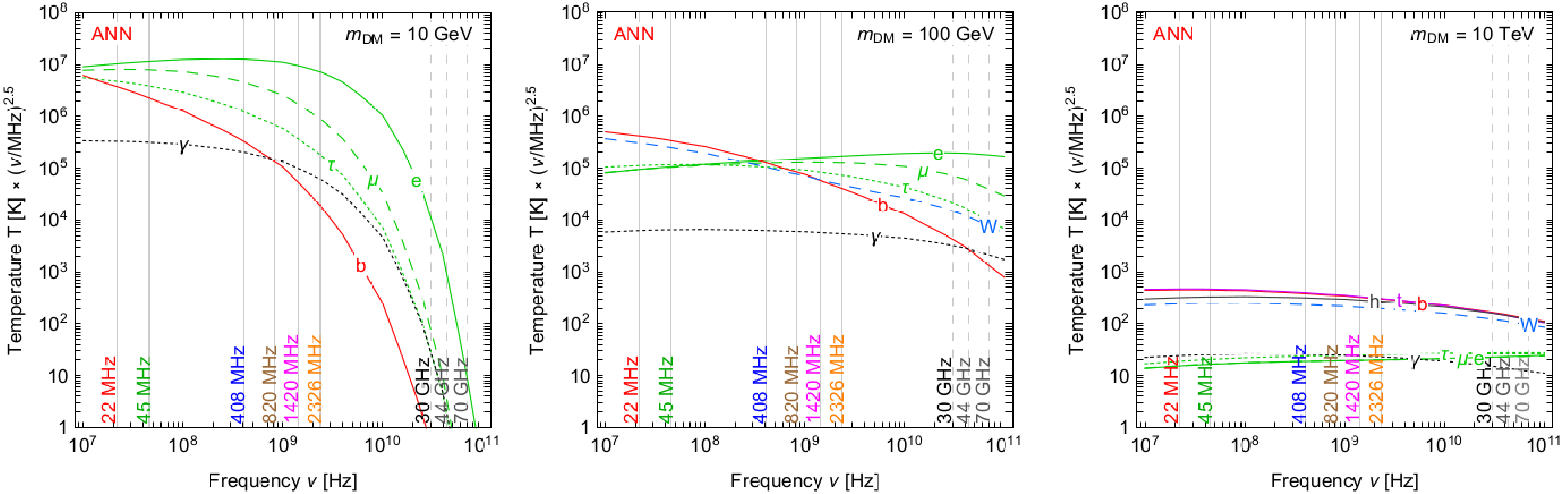


9 data sets

From 22 MHz to 70 GHz

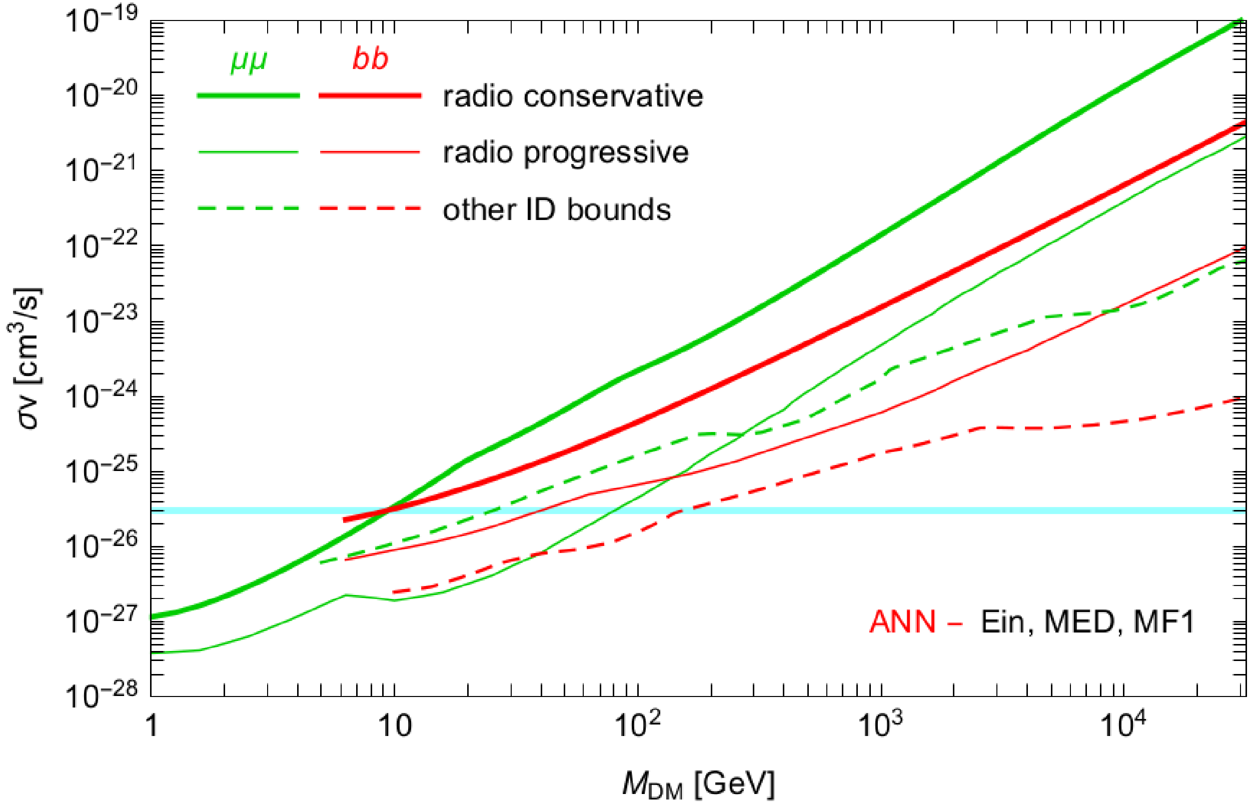
Frequency	*Source and Reference*	*Sky coverage*
22 MHz	Roger et al. [38]	73%
45 MHz	Guzman et al. [39]	96%
408 MHz	Haslam et al. [40]	100%
820 MHz	Berkhuijsen [41]	51%
1420 MHz	Reich et al. [42–44]	100%
2326 MHz	Jonas et al. [45]	97%
30 GHz	PLANCK-LFI [46]	100%
44 GHz	PLANCK-LFI [46]	100%
70 GHz	PLANCK-LFI [46]	100%

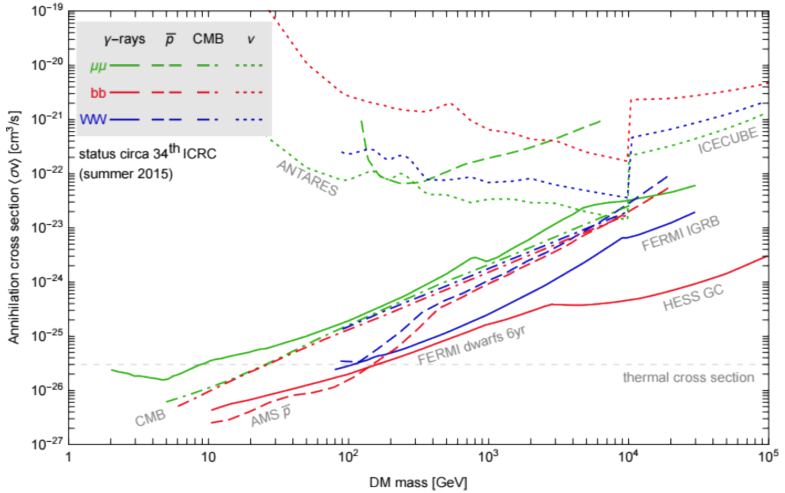
Galactic DM radio emission



DM mass and annihilation spectra reveals the multi-frequency constraining capability

Galactic DM radio emission

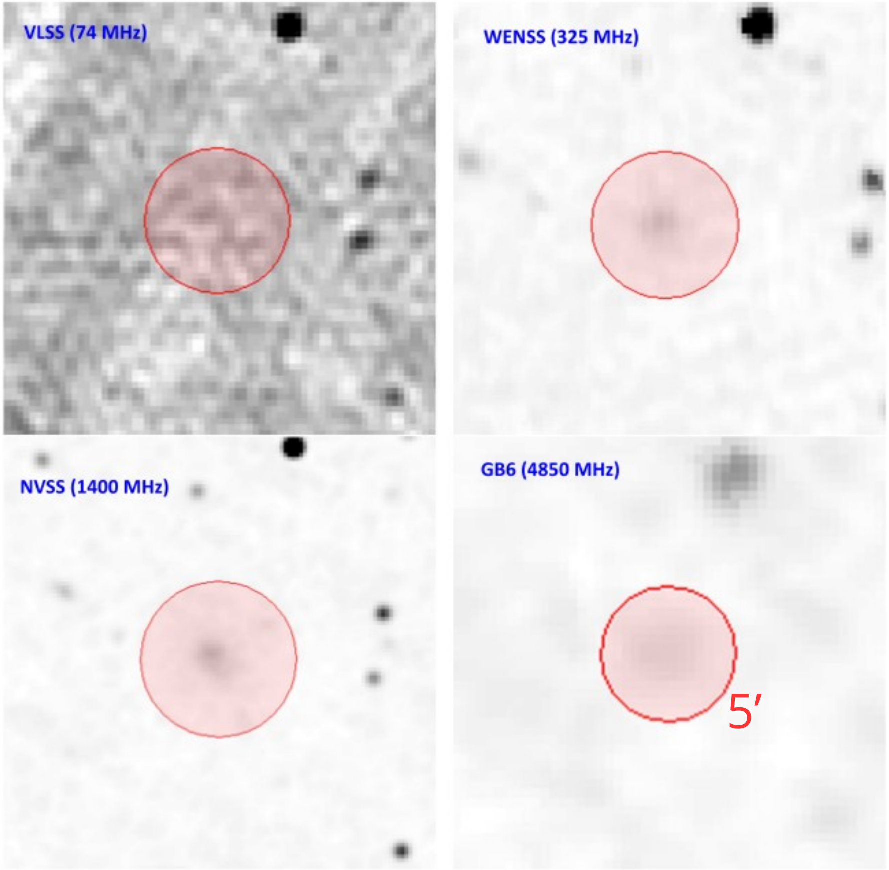




The constraints improve in the progressive scheme

DM radio emission in M31

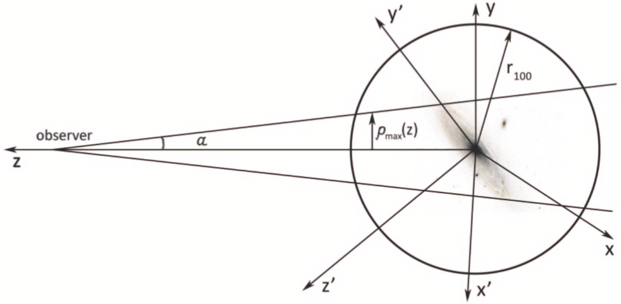
Egorov et al.
arxiv:1304.0517



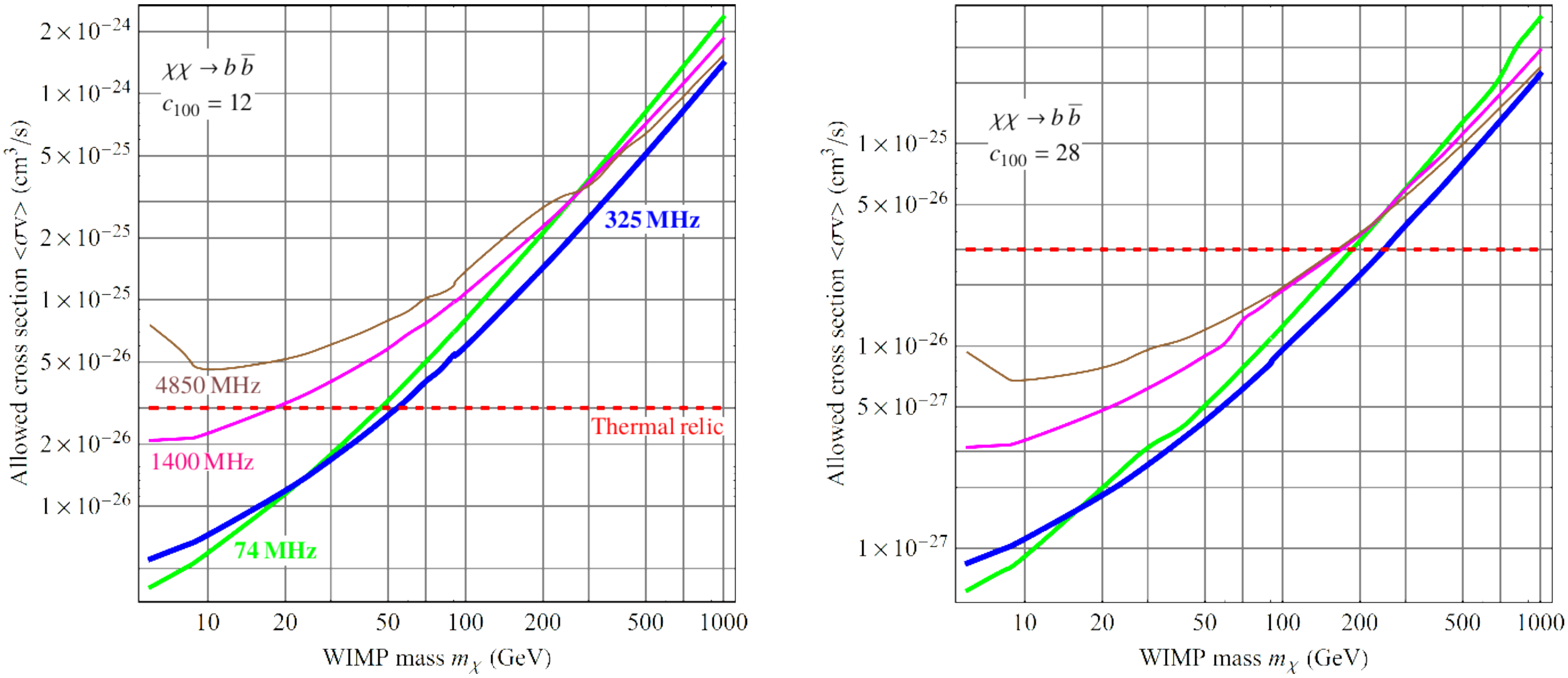
M31 is expected to be very similar to the Milky Way

Analysis based on the central region of M31at frequencies:

74, 325, 1400, and 4850 MHz

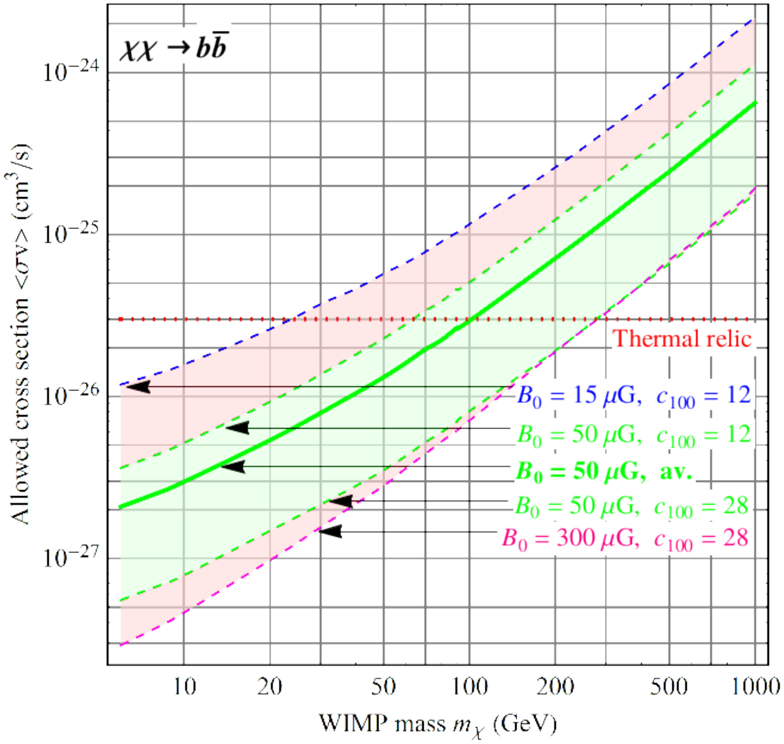


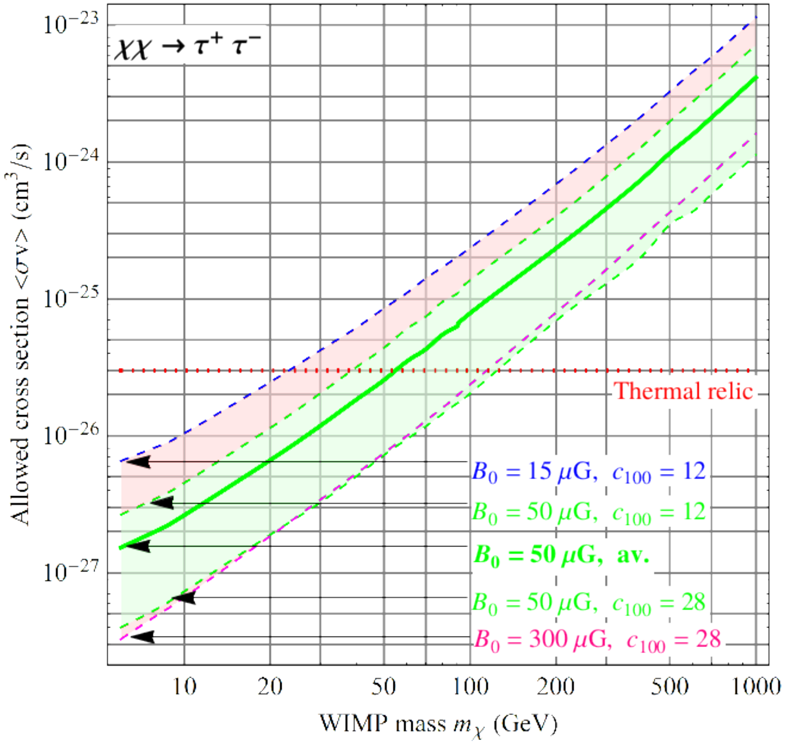
DM radio emission in M31



The concentration value c_{100} has a big impact in the overall signal

DM radio emission in M31



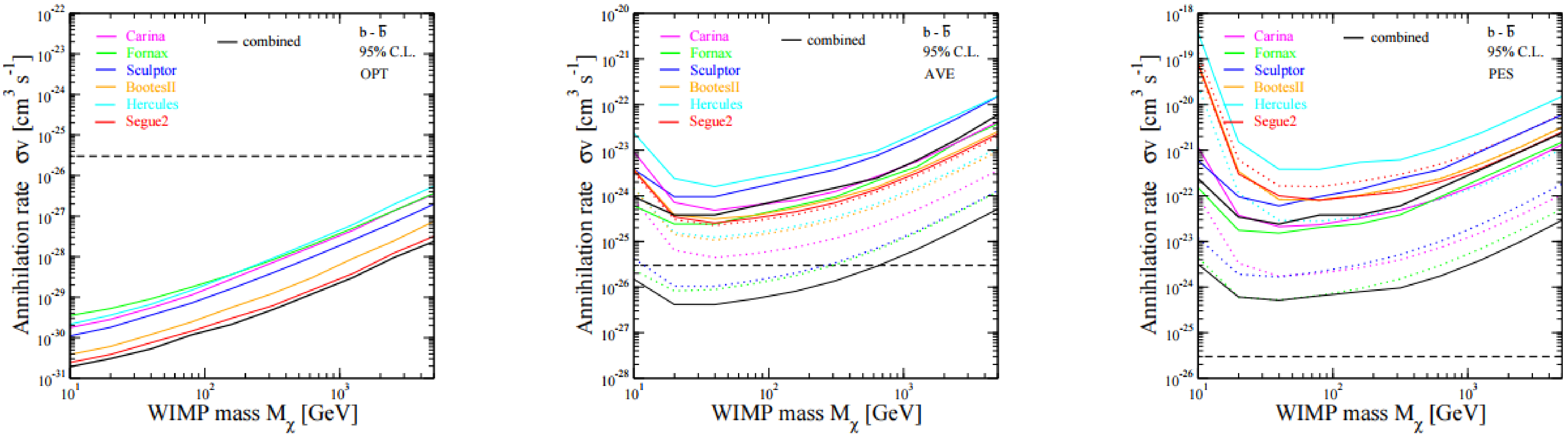


After including uncertainties from DM distribution and magnetic field

Radio from dSph using ATCA

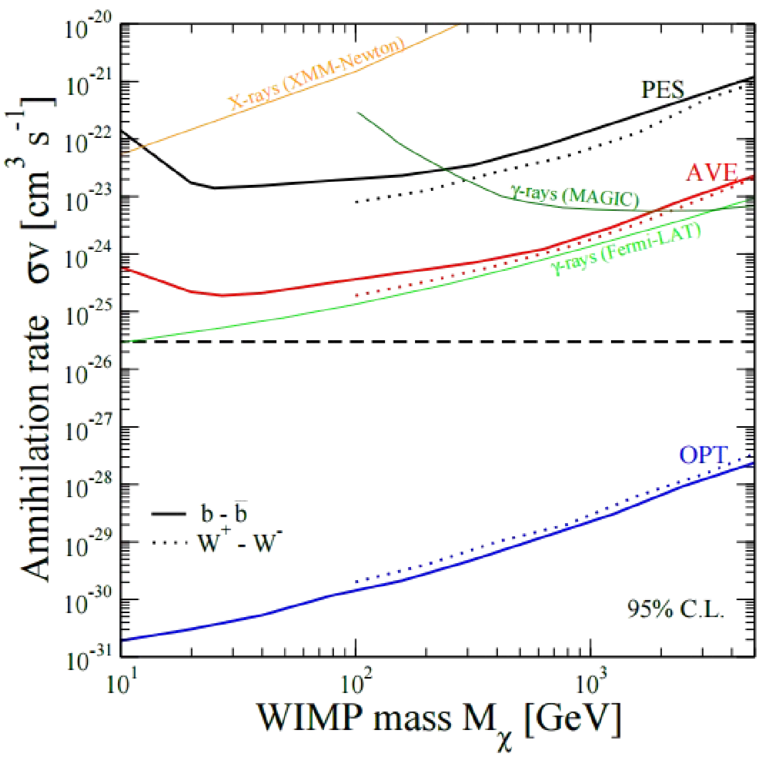
Regis et al
arxiv:1407.4948

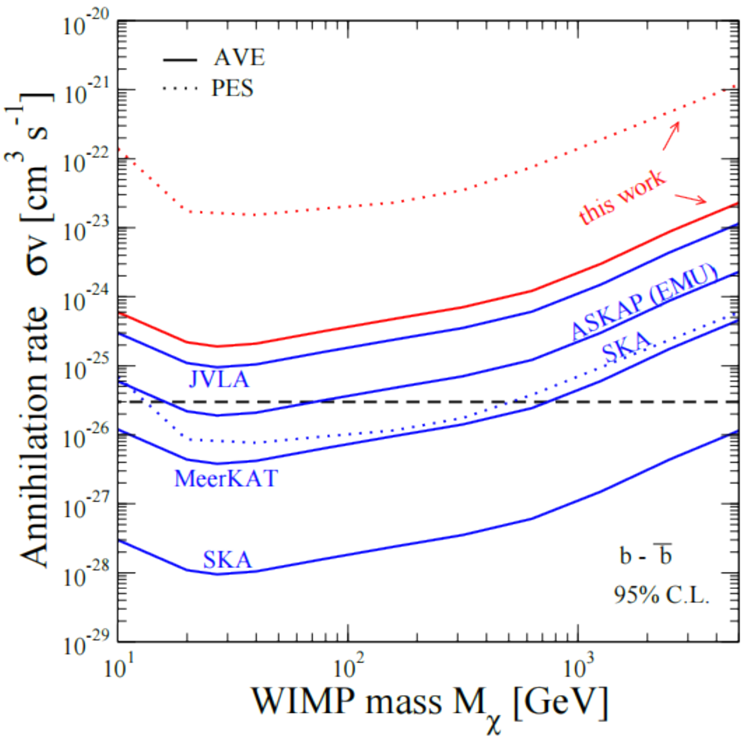
Name	magnetic field	diffusion scheme	DM profile
OPT	B_{eq}^{obs}	loss-at-injection	Einasto
AVE	$\max(B_{\overline{SFR}}, 1\,\mu\mathrm{G})$	$D = 3 \cdot 10^{28}\,(E/\mathrm{GeV})^{0.3} \exp(r/r_*)\,\mathrm{cm}^2/\mathrm{s}$	NFW
PES	B_{SFR_0}	$D = 10^{30}\,(E/\mathrm{GeV})^{0.3} \exp(r/r_*)\,\mathrm{cm}^2/\mathrm{s}$	Burkert



Observation at 16cm over 6 dSph. 3 assumptions. :-), :-|, and :-(

Radio from dSph using ATCA





Constraints from dSph could be very strong with future observation like SKA

The Smith's Cloud

A. Drlica-Wagner et al. 1405.1030

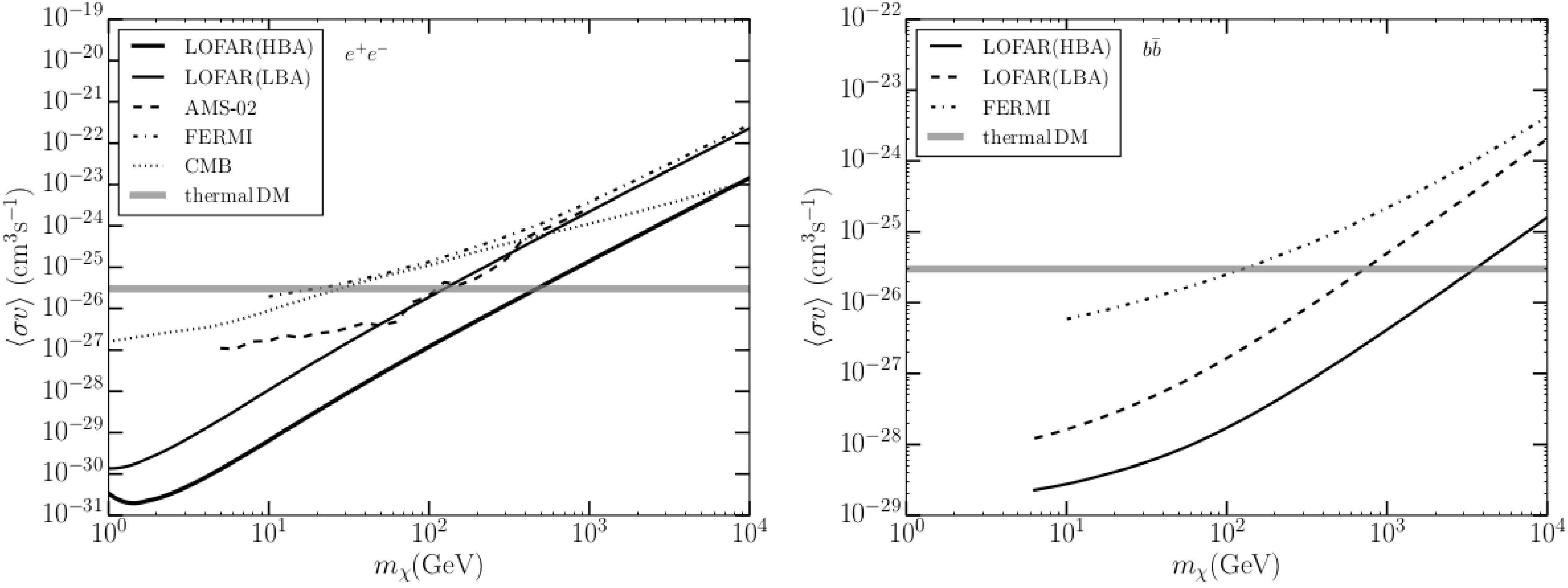
SUMMARY OF SMITH CLOUD DARK MATTER HALO PARAMETERS.

Profile	r_s (kpc)	ρ_0 ($M_\odot$ kpc^{-3})	$M_{\rm tidal}$ ($M_\odot$)	J-factor (GeV^2 cm^{-5} sr)
NFW	1.04	3.7×10^7	1.1×10^8	9.6×10^{19}
Burkert	1.04	3.7×10^7	1.3×10^8	4.2×10^{18}
Einasto	1.04	9.2×10^6	2.0×10^8	1.8×10^{20}

High Velocity Cloud (hydrogen) at ~12.4 kpc from Sun ~2.9 kpc below the Galactic Plane

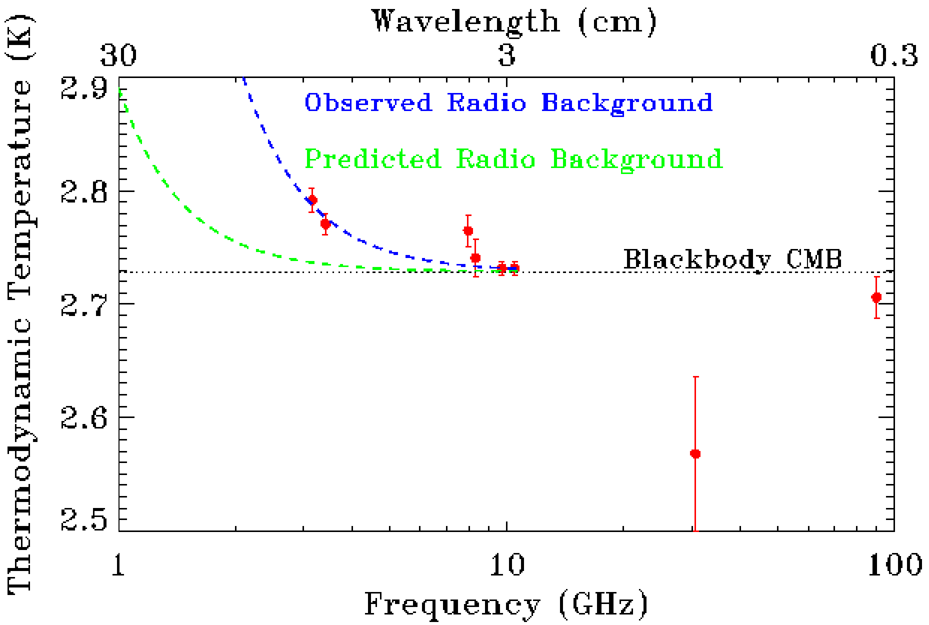
The Smith's Cloud

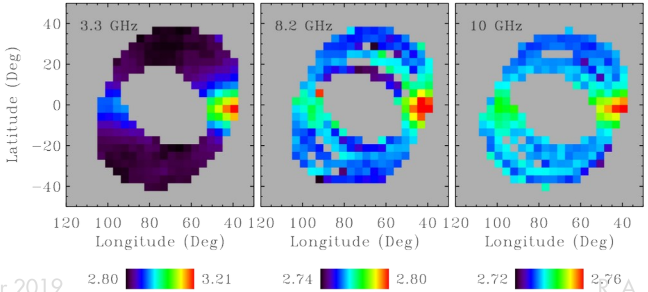
N. Leite et al.
arxiv:1606.03515



Projected LOFAR limits for 8hrs observation time. LBA = 60 MHz, HBA = 150 MHz

Isotropic radio background





They have reported an excess in the radio background which is bigger that the expected with known sources

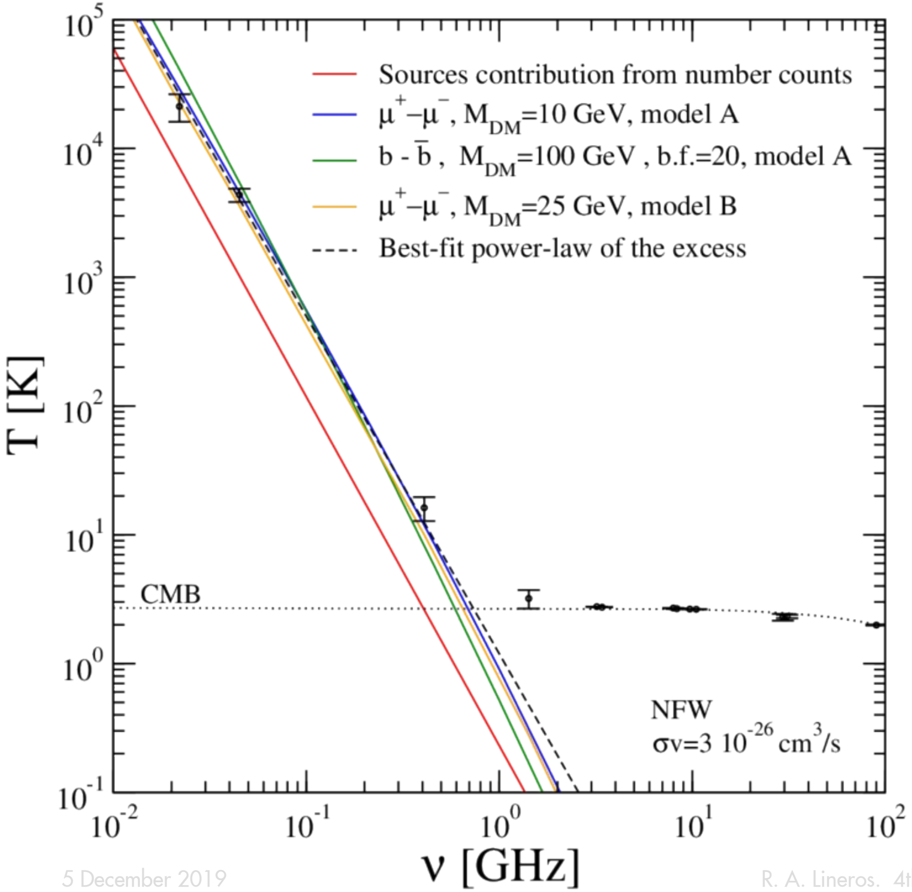
$$T_{sky}(\nu,\alpha,\delta) = T_{\rm cmb}(\nu) + T_{gal}(\nu,\alpha,\delta) + \underline{T_{UERS}(\nu)}$$

Firxen et al. 0901.0555
Seiffert et al. 0901.0559

arcade.gsfc.nasa.gov

Isotropic radio background

PRL 107,271302 (2011), arxiv:1108.0569



DM can provide the missing signal

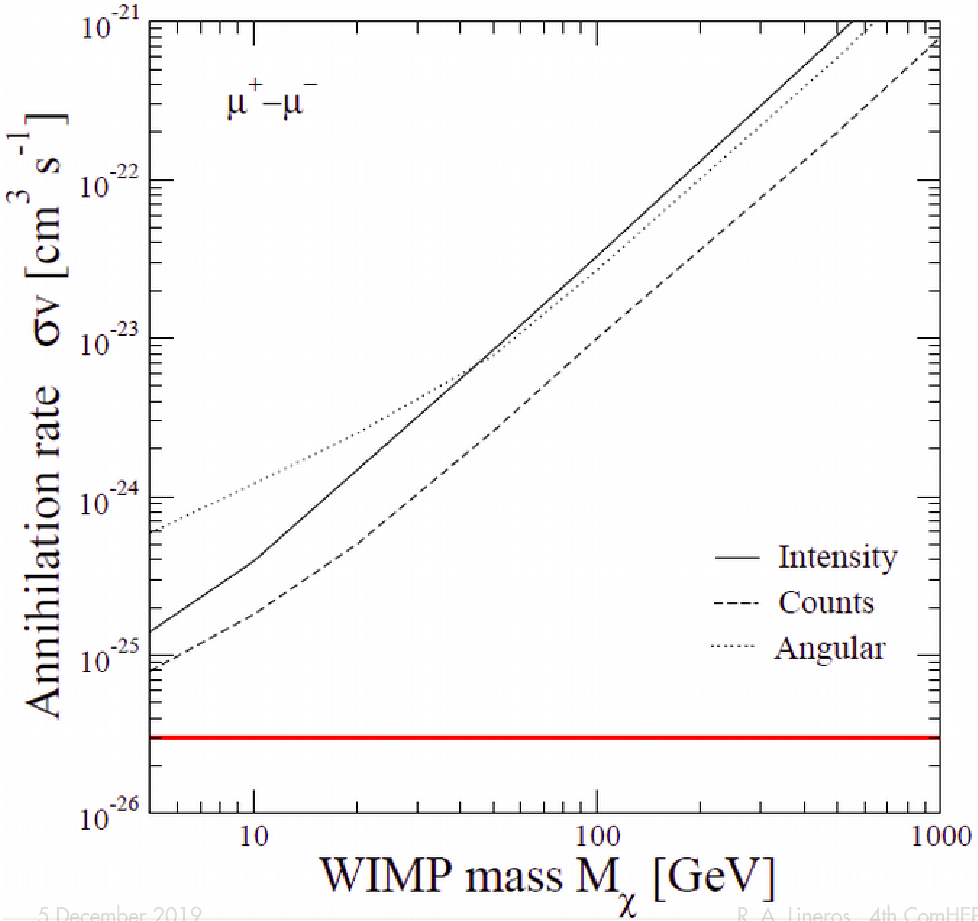
Alternative explanations

- Faint quasars
- Radio-quite AGNs
- Star forming galaxies
- Unresolved galactic sources(?)

More details:
Gervasi et al. arxiv:0803.4138
Singal et al. arxiv:0909.1997

Isotropic radio background

Fornengo et al.
arxiv:1112.4517

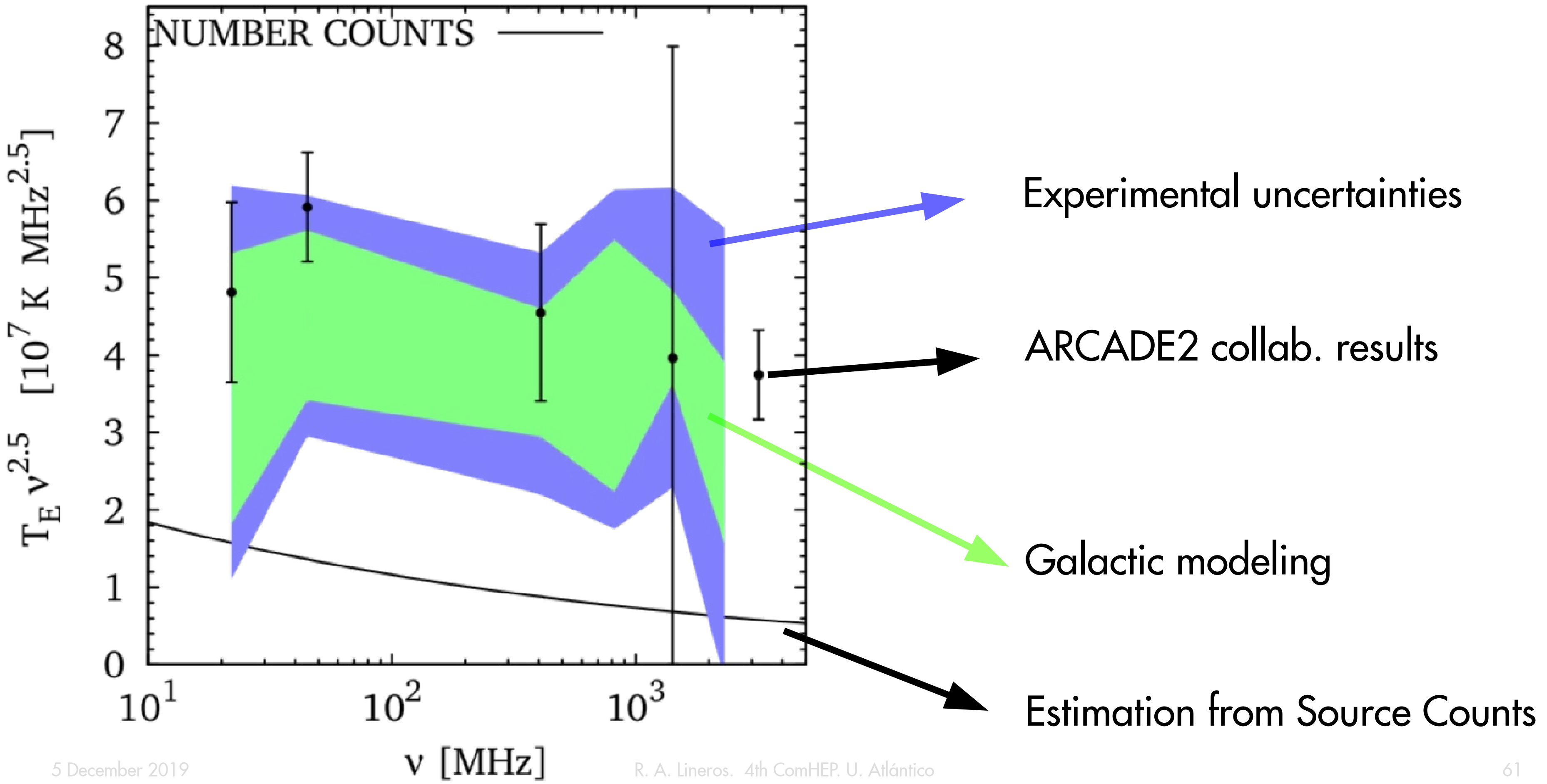


Constraints on the DM contribution can be obtained via

- Intensity
- Source count
- Angular power spectrum

Isotropic radio background

Fornengo et al.
arxiv:1112.4517

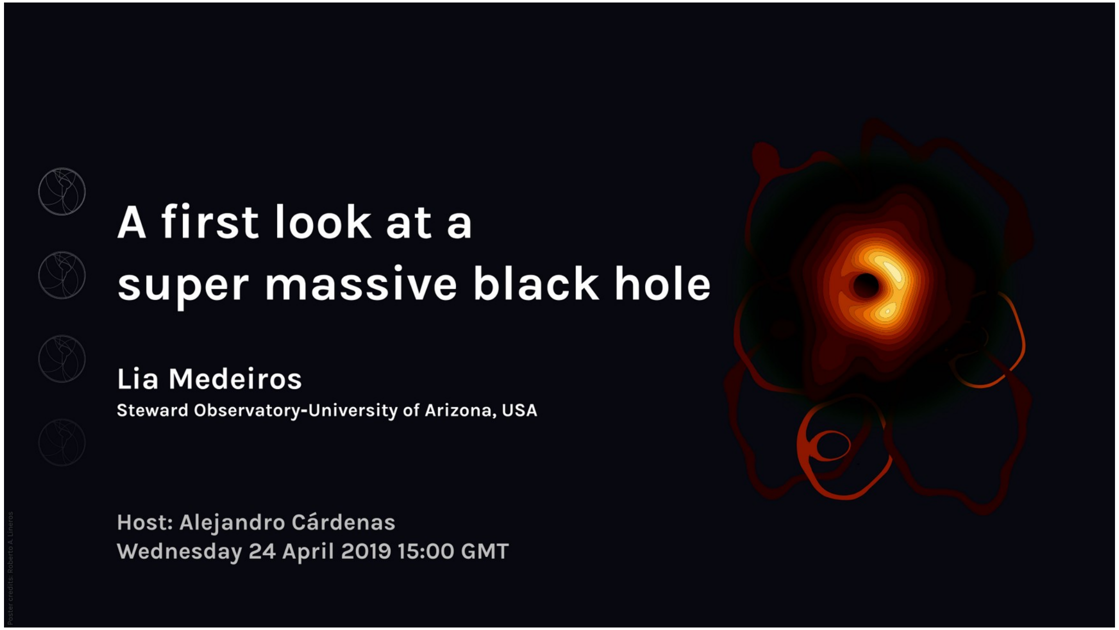


Take home message

- Dark Matter nature is still a puzzle
- Dark Matter candidates in BSM model has to match the observed relic abundance
- Indirect detection and multimessenger analysis are key to unveil DM properties

lawphysics

Latin American Webinars on Physics



/lawphysicsw

/lawphysics

@lawphysics

lawphysics.wordpress.com

Science around Antofagasta

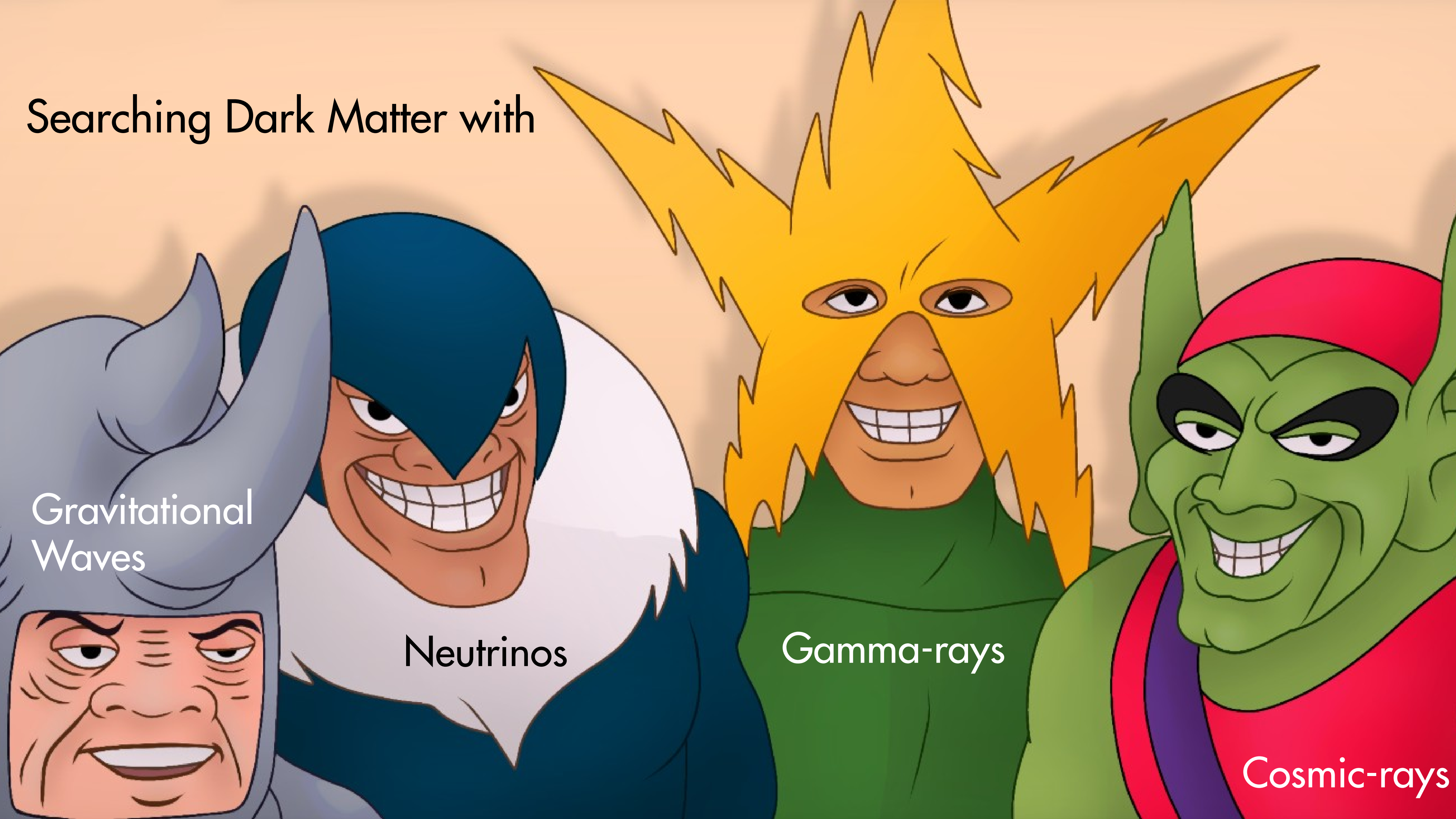

Atacama Large Millimeter Array

MONDian LLAMAS

Milky Way


Cerro Paranal - VLT


Cherenkov Telescope Array


Searching Dark Matter with
Gravitational Waves
Neutrinos
Gamma-rays
Cosmic-rays